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# ADVANCED AUTOMATIC CONTROL STRATEGIES FOR THE ACTIVATED SLUDGE TREATMENT PROCESS

Systems Control, Incorporated

Prepared for
National Environmental Research Center

May 1975

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Results of a demonstration of the feasibility and benefits of applying several advanced wastewater treatment control strategies in an operational treatment plant using a digital computer are presented in this report. The work was conducted in a full size (35 MGD capacity) secondary treatment plant at Palo Alto, California. Control strategies tested were for the secondary treatment portion of the process and involved regulation of aeration tank dissolved oxygen (DO) and food for microorganism ratio (F/M). Two variations of F/M ratio control were evaluated using respectively air flow and a direct measurement of sludge respiration with an on-line respirometer to estimate food (BOD). An extensive data collection program was incorporated which allowed detailed statistical evaluation of each control algorithm with regard to performance, effluent quality impact, operating costs, and reliability, comparison was made to similar data collected during benchmark manual operation tests. Overall results indicate digital control using advanced control concepts is feasible and that demonstrable improvements in effluent quality are obtained. Direct operating cost savings in the form of an 11% reduction in air use was also shown for DO control.

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# FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment - air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- Studies on the effects of environmental contaminants on man and the biosphere, and
- A search for ways to prevent contamination and to recycle valuable resources.

Several control strategies were evaluated during the course of this study to demonstrate the benefits of automatic control of wastewater treatment plants. Improved control of wastewater treatment plants increases plant reliability and thus reduces environmental contamination.

# ABSTRACT

Results are presented in this report of a demonstration of both the feasibility and benefits of applying several, advanced, wastewater-treatment control strategies using a digital computer for data acquisition with a man in the control loop for control implementation. The work was conducted in a full-size (35-MGD (0.13-$Mm^3$/day) capacity) secondary treatment plant at Palo Alto, California.

Control strategies were tested for the secondary treatment portion of the process and they involved regulation of aeration-tank dissolved oxygen (DO) mixed liquor suspended solids control (MLSS) and food-to-microorganism ratio (F/M). Two variations of F/M control were evaluated using, air flow (in one instance) and a direct measurement of sludge respiration with an on-line respirometer (in the other instance) to estimate food (BOD). An extensive data-collection program was incorporated which allowed detailed statistical evaluation of each control algorithm with regard to performance, effluent quality impact, operating costs, and reliability. Comparison was made with similar data collected during benchmark manual-operation tests. Overall results indicate that digital control, using advanced control concepts, is feasible and that demonstrable improvements in effluent quality can be obtained. Direct operating-cost savings in the form of an 11% reduction in air usage were also shown for DO control.

This project was performed by Systems Control, Inc., under contract to the City of Palo Alto, California. The Environmental Protection Agency provided funding under grant number R800356 for the project's demonstration of "Advanced Control Algorithms for the Activated Sludge Process". In addition, the State of California Water Quality Control Board contributed additional funds to the project.

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For Systems Control, Inc., the Project Manager was Laszlo Hajdu and the Project Coordinator was John Meyer. Project support was also provided by Joseph Petersack, Richard G. Smith, Charles Martin, David Stepner and Charles Wells.

# SECTION I

## CONCLUSIONS

The feasibility and benefits of applying several advanced wastewater treatment control strategies in an operational wastewater treatment plant using a digital computer have been demonstrated. The work was conducted in a full-size (35-MGD (0.13-$Mm^2$/day) capacity) secondary treatment plant at Palo Alto, California. Detailed evaluation of each control algorithm with regard to effluent quality impact, operating costs, and plant reliability was made and compared to manual operations. Overall results indicate digital control, using advanced control concepts, is technically feasible. Demonstrable improvements in effluent quality were obtained with the DO control systems. Specific results are summarized below:

Four advanced control algorithms implemented by a man in the loop approach were tested and compared with manual plant operation. They were:

- Dissolved Oxygen (DO) Control
- Mixed Liquor Suspended Solids (MLSS) Control
- Food to Mass of Micro-organism (F/M) Control using Air Flow to infer food and the rate of Returned Activated Sludge (Air/RAS)
- F/M Control using a Respiration Rate measurement to infer food and the rate of Returned Activated Sludge (respirometer/RAS).

A fifth control approach, F/M control based upon TOC loading and rate of returned activated sludge, was attempted but inadequate continuous TOC measurements prevented development of the control approach.

The testing covered both wet and dry-season operation with the first two controllers (and one manual test) in the dry season, and the last two controllers (and a manual test) in the wet season. Dry season tests were conducted with the plant in a new contact stabilization configuration, and wet season tests were conducted with the plant in the conventional, fully mixed, aerator configuration.

The DO controller demonstrated excellent regulating capability in maintaining DO in the aerator at the desired setpoint of 1.0 mg/l. Effluent quality improvement amounted to approximately 7% relative increase in overall secondary removal efficiency based on the four "quality variables" measured - SS, $BOD_5$, TOC, and COD. An 11% reduction in air use was a major quantifiable operating cost benefit. At Palo Alto, this represented a power cost saving of approximately $5,300 per year.

MLSS control was an interim algorithm intended for use in cascade control in other algorithms. Solids levels in the aerators were maintained nearly at set point, except during periods of low plant flow where the lower limit on the RAS pumping caused uncontrolled increases in MLSS. While the effluent quality during MLSS control decreased slightly compared to the manual control period, the plant in the new contact configuration exhibited a gradual change in sludge settleability and developed floating material on the final settlers. This change in sludge character was probably responsible for the slight decrease in plant performance and prompted the reconversion of the plant back to its original, completely mixed configuration for the remainder of the control studies.

The first F/M controller, Air/RAS, with D.O. control, exhibited improvement in the regulation of the variability of the instantaneous F/M compared to that observed during conventional manual operation. But, with the plant operated in the completely mixed configuration, it did not produce completely effective regulation of the F/M. The plant air flow rate with the plant under D.O. control, however, provided a satisfactory indication of plant load changes and correlated well with the manually determined $BOD_5$ in the primary effluent entering the biological reactor. Thus improved and reasonable F/M regulation appears feasible if:

- Adequate sludge storage capacity is provided in the RAS system
- Limitations on high/low RAS pumping rates are removed by plant design changes. (A smaller low limit pumping rate would enable additional sludge storage during periods of low aerator loadings and low plant flows.)

Secondary effluent efficiency during the 28-day Air/RAS control period decreased slightly compared to that during operation with analog man in the loop D.O. control (Manual Test II), but the absolute values of the secondary effluent and the overall plant removal efficiencies remained essentially similar. With the plant's solids inventory and RAS limitations and with the short duration of the control test, realistic evaluation of Air/RAS control approach on plant performance was not achieved.

The second F/M controller, the respirometer/RAS control with D.O. control, also exhibited improved but not complete regulation of the variability in the instantaneous F/M. The respirometer/RAS controller produced the most reduction in the diurnal variability of the instantaneous F/M observed during the entire study and kept all instantaneous F/M values below the point of 0.33 gm of $BOD_5$/day/gm of MLVSS. The controller with the process actually exhibiting an average F/M of about 0.15 gm of $BOD_5$/day/gm of MLVSS, however, did not control to the setpoint F/M and exhibited severe lags of up to 4 hours in responding to process $BOD_5$ load changes.

With unusually efficient primary performance during the respirometer/RAS test period, the % efficiency of the biological secondary process did not change significantly. The best overall plant efficiency and the best absolute effluent quality observed during the entire study occurred during plant operation with the respirometer/RAS control. The apparent improvement, however, is probably not related only or perhaps even chiefly to the application of respirometer/RAS control. During this control test, changes in plant wasting, at the request of the City of Palo Alto, increased the solids inventory in the biological process compared to that during all other operations. The increased inventory both in the reactor and clarifier produced the significantly lower average operating F/M. With the low limit on the plant's RAS pumping rate and with the lags and inaccuracies in the control algorithm, F/M control to setpoint was impossible. Further work is needed to assess the relative effects on plant performance of the reduced variability in the instantaneous F/M and the operation of the plant at a significantly lower average F/M.

Digital computer reliability, after system software development, was excellent. Availability (% of operation time) was over 99%.

Instrument reliability was excellent, for the DO meters and the MLSS meters, with only infrequent calibration checks required. The on-line respirometer was also reliable, but required a somewhat higher level of periodic maintenance for cleaning and for chemicals replacement. The on-line TOC analyzer required extensive calibration and maintenance, and this analyzer will require additional development to be fully acceptable in primary effluent service.

Data management functions developed for the demonstration included automated scanning, logging, and data-base updating. The functions allowed on-line reports, equipment and alarm summaries, and off-line data preparation. Additionally, a set of programs was developed to analyze the data for effective comparative analysis of the various tests. Additional functions included on-line tuning of algorithms and monitoring of control-performance.

# SECTION II

## RECOMMENDATIONS

In general, while existing instrumentation (except for the TOC control approach) is sufficiently reliable to implement the advanced control algorithms that were demonstrated, sensor development should be encouraged for on-line monitoring and control.

Specific recommendations are:

1. Develop specifications and design guidelines for closed loop DO control systems in fully mixed aerators to realize energy savings and improved effluent quality.
2. Make further explorations using pilot-plant process-development studies directed toward improving instantaneous F/M control. Among the areas to investigate are the impact of separate sludge storage and the results to be expected for plug-flow reactors.
3. Evaluate the possibilities for, and benefits of, controlling other plant functions from the computer such as:
   - Activated sludge wasting
   - Chlorine dosage
   - Digester temperature
   - Sludge solids handling
4. Determine optimum methods for computer information display and operator interfacing to improve monitoring and control of the plant. More frequent and higher quality data will speed trouble diagnosis and improve productivity by having the computer perform the routine data-reporting functions.
5. Continue testing of on-line analytical instrumentation, especially for the quantities TOC, COD and low-level (less than 50 mg/l) suspended solids. Evaluation should place emphasis on reliability with minimum maintenance and calibration requirements.

Less quantifiable, but potentially more significant, operating cost savings were not addressed in this study, but they should ultimately be considered when determining the cost/benefit tradeoffs for these controllers. Among the areas of definite further savings are:

- Manpower Productivity - More effective manpower utilization is possible with closed loop automatic control because such control relieves operators of time-consuming adjustments of process-monitoring and control devices.

- Incremented Capacity Costs - Improved effluent quality may be translated into increased plant capacity. This could result in a delay or reduction in planned expansion of facilities with a resultant sizeable savings in capital investment costs.

A detailed economic-investment analysis, including estimates of these and other factors, is necessary before the true net cost of an operational control system, be it analog or digital, can be ascertained.

## SECTION III

## INTRODUCTION

### SCOPE AND PURPOSE OF THE DEMONSTRATION PROJECT

The Palo Alto Automation Project demonstrated the feasibility of using man in the loop digital computer control to implement several advanced control schemes for the activated sludge process of a wastewater treatment facility. Control algorithm designs were selected to achieve improvements in waste removal efficiencies as well as reductions in operating costs. Extensive computerized data collection and analysis were employed to evaluate each control system for a 30 day experimental test period. Two 30-day tests were also performed in which conventional plant operation was employed. The manual control periods provide comparison data for both wet and dry season operation. A three-day intensive, data-collection period at the end of each 30-day test was used to obtain information for detailed hour-by-hour evaluation of control system performance.

Control strategies examined were concerned with the secondary treatment, or activated sludge portion of the plant. Basically, the various experiments fall into two categories:

1. Control of dissolved oxygen concentration in order to minimize aeration costs.

2. Control of the ratio of waste utilization to microorganism concentration (Food to mass, F/M) in an attempt to improve waste removal efficiency by following the daily variations in plant loading.

The objects of this demonstration were to indicate the advantages and some of the costs associated with computer automation of some phases of operation for this type of treatment plant. Also, comparison data is developed to indicate how successfully the new process control schemes improved removal efficiencies and/or reduced operating expenses. The implications of the results have broad impact since this project, although carried out in a new plant (start-up October, 1972), involved installing a computer and associated automation related instrumentation in a plant not specifically designed for computerized data logging and automatic control.

### DESCRIPTION OF PALO ALTO REGIONAL TREATMENT FACILITIES

The Palo Alto plant is a regional facility serving the cities of Palo Alto, Mountain View, Los Altos, and Stanford University. Waste is primarily domestic at present, although a batch process industrial treatment facility is to be placed in operation shortly. Plant design capacity is 35 MGD (0.13 $Mm^3$/day) and current operation is in the 25 MGD (0.095 $Mm^3$/day) to 30 MGD (0.115 $Mm^3$/day) range. The plant is a conventional, secondary treatment plant with final effluent chlorination. After primary sedimentation, the waste is treated in an activated sludge process employing clarifiers for activated sludge recycle. Current loading of $BOD_5$ is about 30 to 40 thousand pounds per day.

For this study the secondary portion of the plant was modified to operate in a contact stabilization configuration to provide an inventory of sludge. Both the contact and the aeration basins were completely mixed. However, operational difficulties with the contact stabilization configuration at Palo Alto forced revision of the operation to the original plant design configuration, completely mixed aeration. Consequently, in the report the secondary portion of the plant is described for two modes of operation.

Sludge disposal is accomplished by means of incineration and ash dumping in a nearby solid refuse area. Pre-incineration dewatering is carried out in sludge thickening tanks and then by centrifuging. A schematic diagram of the plant process, minus the centrifuges and incinerators, is given in Figure 1. Figure 2 is a diagram of the plant physical layout.

The secondary portion of the plant can be operated in two modes.

1. Conventional (completely mixed) (Figure 3)

2. Contact Stabilization (Figure 4)

In the conventional mode, all four aerators and associated clarifiers are employed in parallel as fully mixed reactors. Return activated sludge is pumped directly from the final clarifiers back to the primary effluent channel. For contact stabilization, one aerator is converted to a sludge storage and reaeration basin and the associated clarifier is taken out of service. The stabilization basin serves the remaining three aeration basins operated in parallel. Aerators and clarifiers are linked one to one with no cross-coupling. In the contact mode, return activated sludge is pumped from the clarifiers to a sludge storage tank, and from there flows by head differential back to the primary effluent channel. In both modes of operation, sludge wasting was achieved by wasting mixed liquor from the aerators directly to the thickeners.

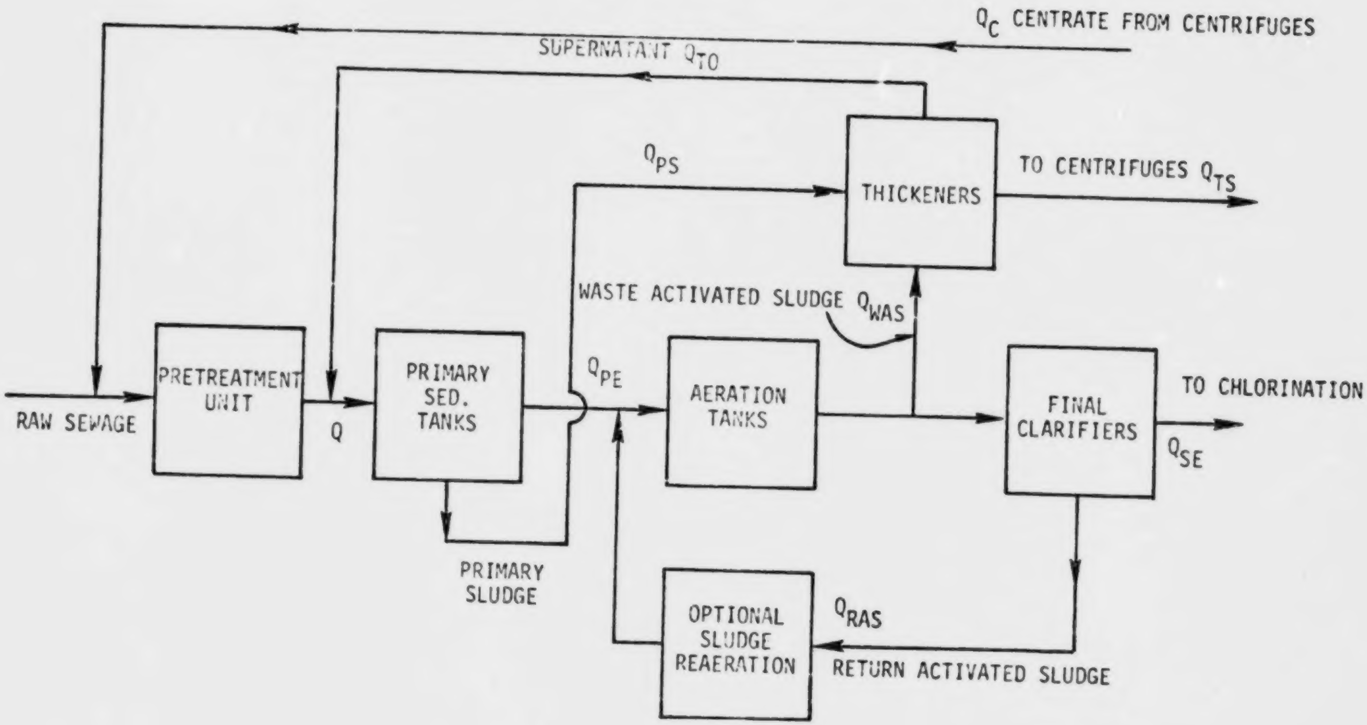
$Q_C$ CENTRATE FROM CENTRIFUGES
SUPERNATANT $Q_{TO}$
$Q_{PS}$
THICKENERS
TO CENTRIFUGES $Q_{TS}$
WASTE ACTIVATED SLUDGE $Q_{WAS}$
RAW SEWAGE
PRETREATMENT UNIT
$Q$
PRIMARY SED. TANKS
$Q_{PE}$
AERATION TANKS
FINAL CLARIFIERS
TO CHLORINATION
$Q_{SE}$
PRIMARY SLUDGE
OPTIONAL SLUDGE REAERATION
$Q_{RAS}$
RETURN ACTIVATED SLUDGE

FIGURE 1. SCHEMATIC FLOW DIAGRAM OF THE PALO ALTO SEWAGE TREATMENT PLANT

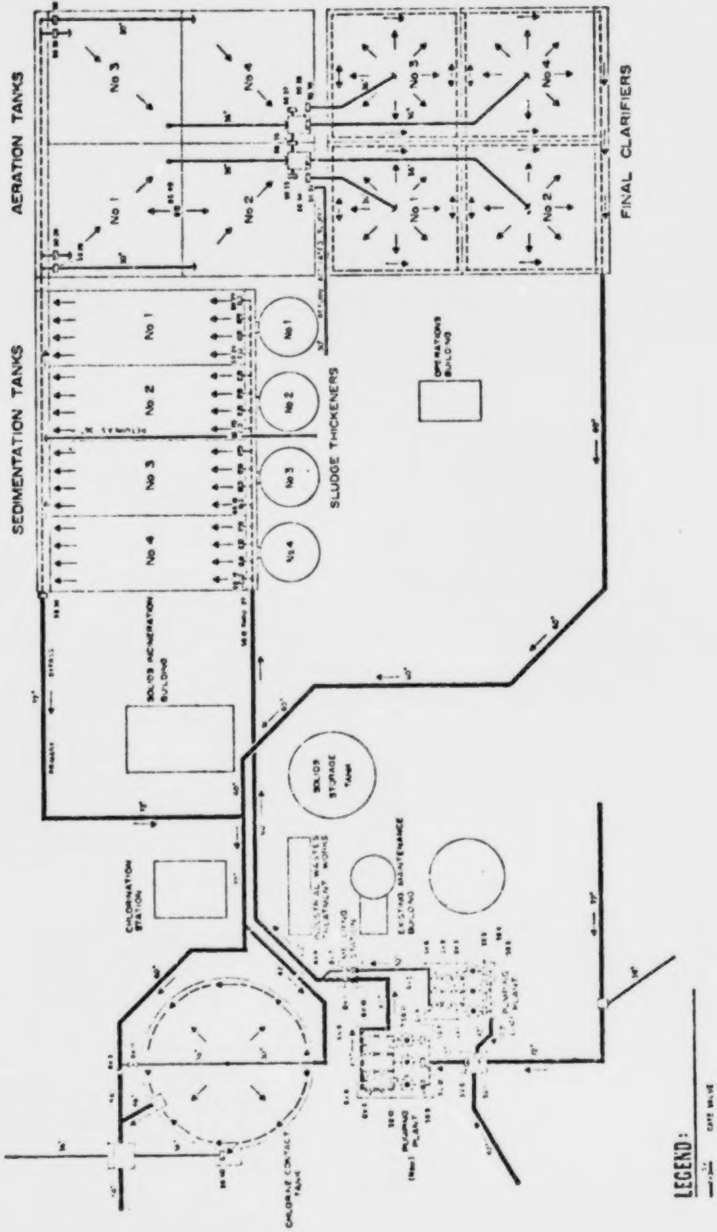
AERATION TANKS
No 1
No 2
No 3
No 4
SEDIMENTATION TANKS
No 1
No 2
No 3
No 4
SLUDGE THICKENERS
No 1
No 2
No 3
No 4
FINAL CLARIFIERS
No 1
No 2
No 3
No 4
OPERATIONS BUILDING
SOLIDS GENERATION BUILDING
SOLIDS STORAGE TANK
CHLORINATION STATION
INDUSTRIAL WASTES TREATMENT WORKS
EXISTING MAINTENANCE BUILDING
PUMPING PLANT
CHLORINE CONTACT TANK
LEGEND:
GATE VALVE
SLIDE GATE
BUTTERFLY VALVE

FIGURE 2. SEWAGE FLOW DIAGRAM

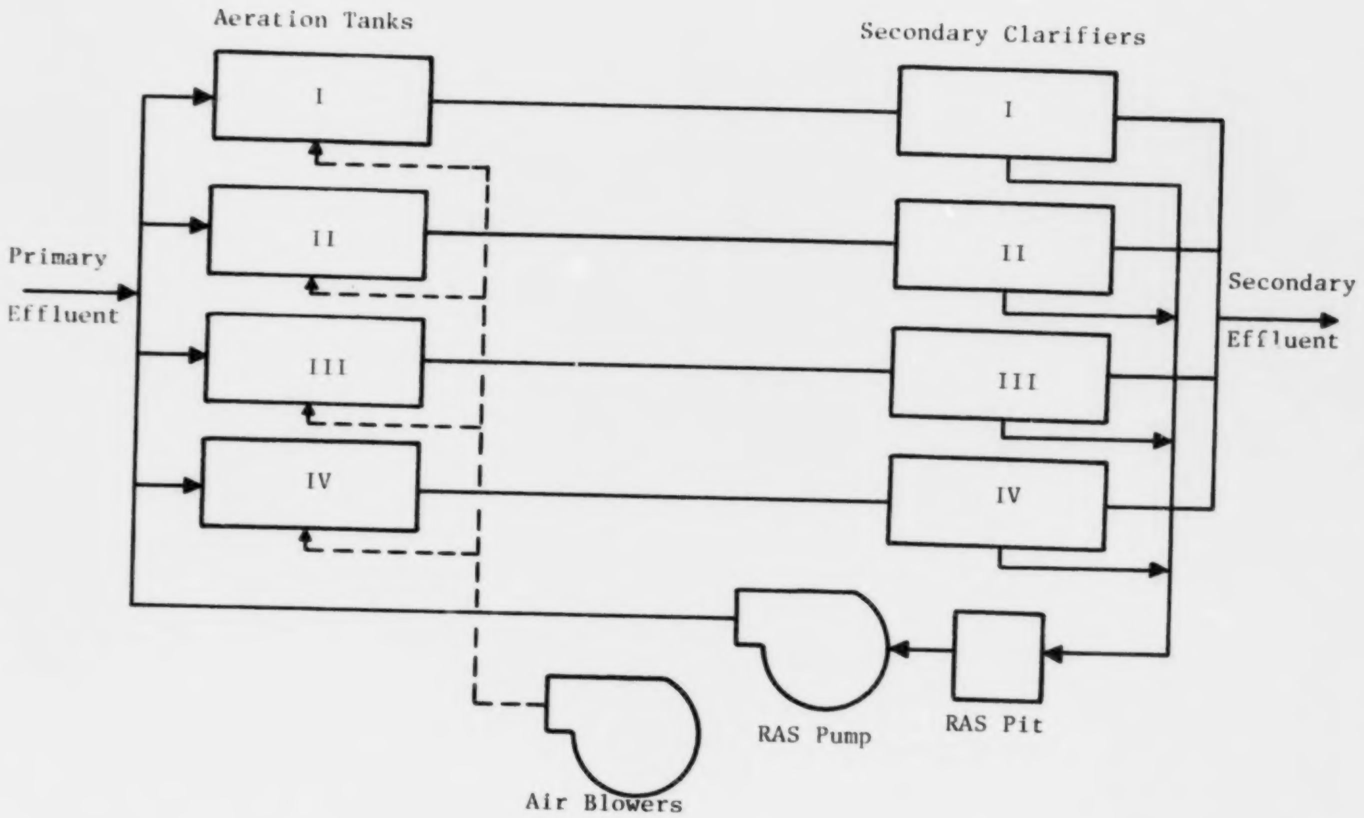
Aeration Tanks
Secondary Clarifiers
I
II
III
IV
I
II
III
IV
Primary
Effluent
Secondary
Effluent
RAS Pump
RAS Pit
Air Blowers

FIGURE 3. PROCESS FLOW SHEET FOR THE ACTIVATED SLUDGE (CONVENTIONAL MODE)

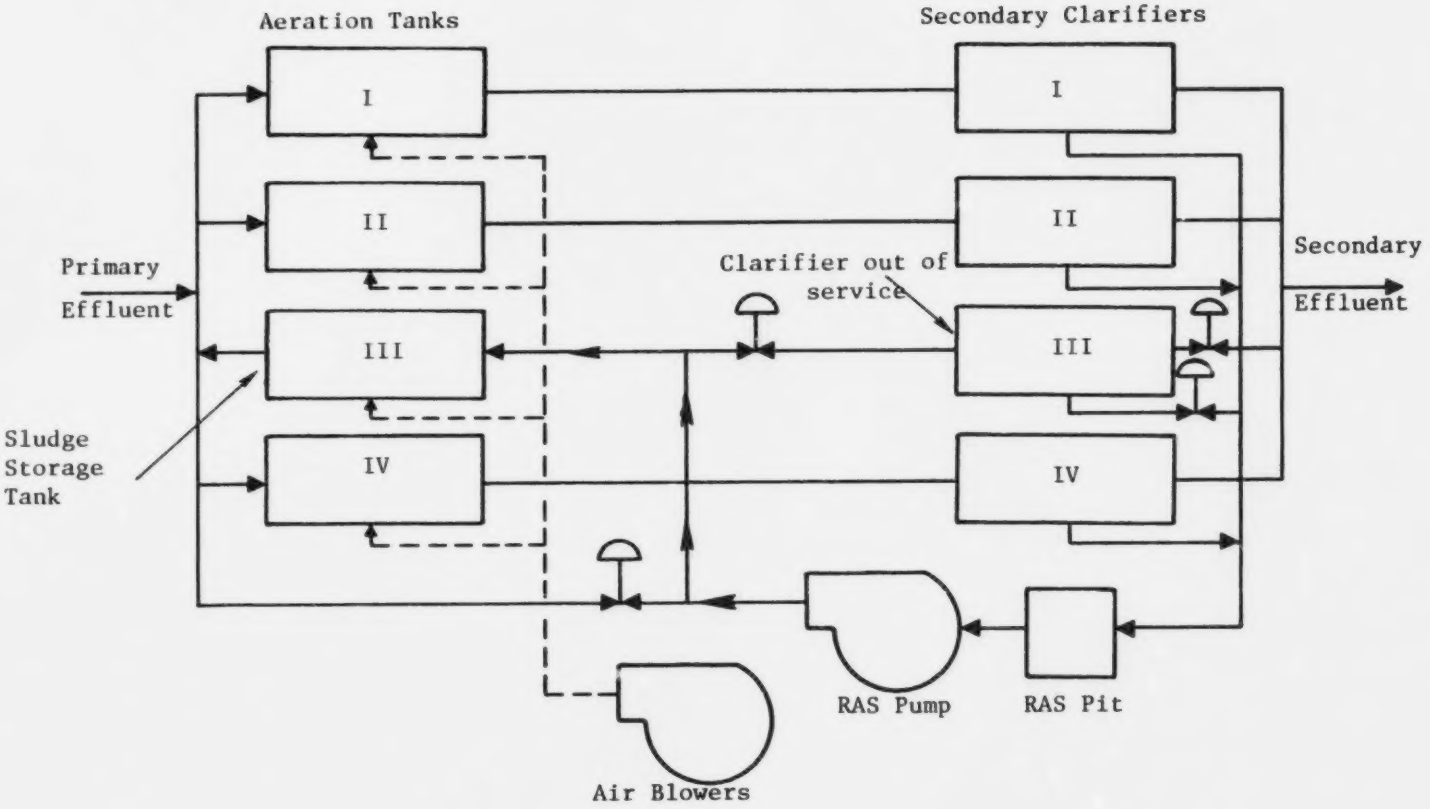
Aeration Tanks
Secondary Clarifiers
I
II
III
IV
I
II
III
IV
Primary Effluent
Secondary Effluent
Clarifier out of service
Sludge Storage Tank
RAS Pump
RAS Pit
Air Blowers

FIGURE 4. PROCESS FLOW SHEET FOR THE ACTIVATED SLUDGE SYSTEM (CONTACT STABILIZATION MODE)

# SECTION IV

## PHASES OF THE PROJECT

The Palo Alto Computer Project was divided into the following phases:

- Computer Installation
- Software Development
- Instrument Installation and Checkout
- Control Algorithm Design
- Control Algorithm Evaluation

The first two phases, computer installation and system software development, were done in sequence, and their completion was required in order to effectively carry out the remaining phases. The remaining phases, instrument installation and checkout, control algorithm design, and control algorithm evaluation were carried out concurrently with respect to each control system.

Installation of the computer system involved provision for proper power and grounding, the layout, design, and connection of process signals, and checkout of all components of the system. The computer was an IBM System/7, with 16K words of main storage and 2.5 million words of disk storage. Additionally, a teletype, a card reader, and a magnetic tape drive were provided. The analog/digital subsystem consisted of 32 analog inputs, 80 digital inputs, and 32 digital outputs.

The system software development was a joint effort between IBM and Systems Control, Inc. An IBM Systems Engineer was assigned to work onsite to develop the necessary software. The principal components of the system software were:

- Scan
- Limit Check and Alarm
- Disk Write
- Log
- PAX Monitor

The most significant effort was the development of the PAX monitor. The program was the operating system that allowed foreground/background processing. Thus, new control systems and data management programs could be added and tested concurrently with existing scan and control programs.

The instrument installation and checkout phase involved both existing instruments (as per original plant construction), and new instrumentation. The existing instrumentation included for control were:

- Magnetic Flow Meters
- Air Flow Meters
- D.O. Probes

These instruments had to be calibrated and checked periodically as part of the scan computer program. The additional instrumentation particular to this project included:

- Suspended Solids Meters
- Respirometer
- TOC Analyzer

These instruments also had periodic maintenance and calibration requirements in addition to initial installation and checkout.

There were five major control systems designed for the full-scale, activated sludge, treatment plant at Palo Alto. Each control system was intended to demonstrate the automation of certain functions within the process. The goal was to show that an automatic control system will aid the operator in improving the overall quality of the plant effluent and/or demonstrate some reduction in operating costs. The major control schemes were:

- Aeration Tanks DO Control
- Aeration Tanks Control
- F/M Control using Air Flow Rate as a Measure of Food Uptake with DO control (Air/RAS)
- F/M Control using Respiration Rate as a Measure of Food Uptake with DO control (Respirometer/RAS)
- F/M Control using Primary Effluent TOC as a Feedforward Measure of Food Uptake with DO control (TOC/RAS)

Improved removal efficiency was expected because the microbiological growth environment within the secondary system is more closely regulated under automatic control. The diurnal variations of flow and organic loading generally cause fluctuations in F/M values and oxygen transfer rates, which in turn reduce the overall efficiency of the plant. If, on the other hand, the oxygen transfer driving force (DO concentration) and the F/M are maintained at constant values, the growth environment is optimized, and consequently more soluble organic material will be oxidized.

Operating costs benefits can be realized since, by following the fluctuations in loading, equipment power usage can be reduced in off-peak hours. A constant level of operation, by contrast, will necessarily consume larger amounts of electricity than is actually required for off-peak BOD loads, and therefore excess capacity is being used unnecessarily for a significant amount of the time.

Evaluation of control algorithms was performed by analyzing extensive process and laboratory data collected over a 30-day test period for each controller. Similar data representing manual operation for equivalent periods was also collected and used for comparison purposes. Process data was automatically monitored and logged every two minutes by the computer. Laboratory results were composed of composite daily samples of important plant process streams for 27 days of non-intensive testing and bi-hourly samples for the last three days of intensive testing.

Intensive test data allowed evaluation of the controller performance in regulating tasks through the diurnal changes in loading and flow. Month-long summary data provided the means for comparing average values of:

- Removal Efficiencies
- Absolute Levels of Effluent Contaminants
- Operating Costs

Controllers were first evaluated for their success in achieving their design goal (DO regulation, MLSS regulation, F/M regulation). Then, judgment was made of that control-design goal's impact on effluent quality improvements and/or operating cost savings as compared to manual operation. Finally, the benefits, if any, derived from a particular control algorithm were weighed against all the costs of implementing that control to determine if it was indeed advantageous for waste water treatment.

## SECTION V

## CONTROL ALGORITHM DESIGN

Control algorithms for the various experiments were designed for, and implemented on, a digital computer with direct input of process instrumentation measurements. Algorithms incorporated features designed to handle such real-time control constraints as measurement availability, smooth manual-to-automatic transition, and limited control authority, as well as accomplishing the performance design goals for each control strategy. For the demonstration project, however, the actual control action was not performed directly by the computer; rather, a plant operator was notified of desired control action whenever the process variable exceeded selected limits. The operator would then make the necessary corrections as indicated by the computer. This "man in the loop" procedure was adopted for these reasons:

- With the experimental nature of the strategies, it was felt some judgment should be exercised before a control action was made.

- Since the plant was not specifically designed for automatic operation, existing blower, pump, and valve-control devices are not amenable to direct computer operation without considerable additional equipment.

The mathematics of the control schemes, dissolved oxygen control (DO), and mixed liquor suspended solids control (MLSS) are independent of the two plant operating configurations. Both the DO and the MLSS control strategies were evaluated in the modified contact stabilization mode. The remaining schemes, air flow rate as a measure of food uptake (Air/RAS) and respiration rate as a measure of food uptake (Respirometer/ RAS) were evaluated in the completely mixed configuration because of operating difficulties with the modified contact stabilization configuration.

### DISSOLVED OXYGEN CONTROL

The system for maintaining sufficient DO in the completely mixed aerators of the contact configuration is shown schematically in Figure 5*. It is desirable to keep the DO at a level in the range between 0.5 and 1.5 mg/l for most efficient operation. Effluent quality deteriorates for lower DO levels due to problems related to microorganism death or changes in culture which may lead to bulking sludge. Excessive aeration can create poor sludge-settling characteristics as a result of floc shearing or changes in microorganism culture, and effluent quality is again adversely affected.

*Note: the DO controller can be used, without alteration either for the contact stabilization or conventional modes of operation.

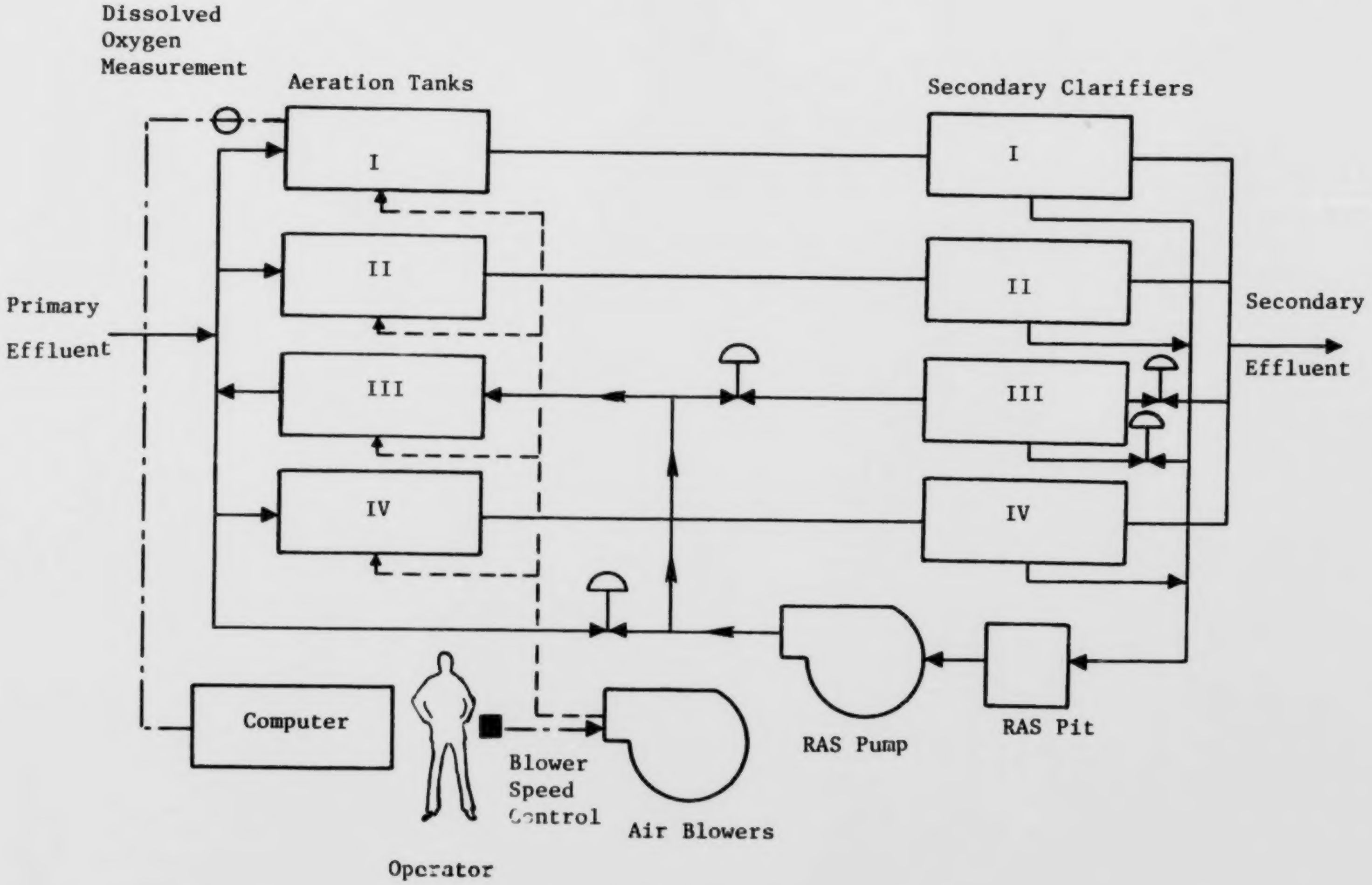
Dissolved
Oxygen
Measurement
Aeration Tanks
Secondary Clarifiers
I
II
III
IV
I
II
III
IV
Primary
Effluent
Secondary
Effluent
Computer
Blower
Speed
Control
Air Blowers
Operator
RAS Pump
RAS Pit

FIGURE 5. SCHEMATIC DIAGRAM OF OXYGEN CONTROL SYSTEM (ILLUSTRATED FOR CONTACT STABILIZATION MODE)

Within the above mentioned range, variation in the DO level does not have a significant bearing on effluent quality. However, increased costs are incurred in supplying additional air to hold a higher DO level than the minimum level for satisfactory treatment. Since oxygen consumption is dependent on the condition of the biological mass and on the BOD loading which varies throughout the day, the air supply rate must be varied to achieve the constant DO level necessary for best cost efficiency consistent with good treatment. The DO controller changes the airflow rate automatically in response to changing oxygen demands and thereby maintains the desired optimum DO level.

Figure 5 indicates that the DO control algorithm was set to control the air flowrate to only a single aeration tank based on the measurement of DO in the tank. The distribution of air to the other three tanks, and therefore the maintenance of an acceptable DO level, was performed by periodic manual adjustment of the butterfly valves such that all DO levels on the tanks used for aeration were equal. Separate control loops for each aeration tank were not feasible at Palo Alto since there was no convenient way of independently adjusting the four airflows.

In essense, the DO control algorithm was a conventional proportional-plus-integral (PI) process control mechanism operating on the DO measurement from one aeration tank. The control mechanism for changing air flow rate to equal the calculated control demand was carried out by altering the air blower speeds. Changing the blower speeds in response to commanded flow changes for one aerator altered the air supply to all aerators in approximately the same proportion, thus maintaining nearly equal DO levels in all tanks. As discussed earlier, implementation of the control commands was through the plant operators who were responsible for actually setting the computer-calculated flow rates by adjusting blower rates and/or putting blowers in and out of service.

Control algorithm computations carried out in the computer to determine the air flow rate necessary to maintain the desired DO level begin with the raw DO signal-inputs to the computer. This signal was sampled at 6 second intervals by the A/D system. A digital first order equation having the form

$$DO_{f_n} = DO_{f_{n-1}} + (1-\alpha)DO_{raw_n} \qquad (1)$$

processes this 6 second data, further reducing the high-frequency noise content to yield a smoothed measurement, $DO_f$. The value $\alpha = .97$ was used; this value is equivalent to a filter time constant (T) of 3.5 minutes. The relationship between the averaging factor ($\alpha$) and the time constant (T) can be found from the following derivation.

$$DO_f = \frac{DO_f}{T} + \frac{K}{T} DO_{raw} \qquad (2)$$

where T is the filter time constant and K is the gain. With a sampling interval of Δ minutes, the solution for $DO_f(t + \Delta)$ in terms of $DO_f(t)$, where t is real time and s is a dummy integration variable,

$$DO_{f(t+\Delta)} = e^{\frac{\Delta}{T}} DO_f(t) + \left( \int_0^{\Delta} e^{\frac{s}{T}} \, ds \right) DO_{raw}(t) \qquad (3)$$

for the assumption that $DO_{raw}(t)$ is constant over $(t, t+\Delta t)$. With a 6 second scan time ($\Delta = 1/(10)$ minute)), the equation for α at a time constant of T minutes, is

$$\alpha = e^{-\frac{\Delta}{T}}.$$

The algorithm used on the DO signal is the 'velocity' form of the PI algorithm requiring the controlled variable error value and first derivative. This form eliminates the problems of "wind-up" that can result with control authority limitations and integral control action. A polynomial filter is used to obtain the required derivative of the filtered DO signal. This filter uses the past four filtered DO values and fits a second order polynomial to the values to minimize the mean square residuals. In equation form, this is

$$\hat{DO}_{t-s} = \sum_{i=0}^{2} a_i s^i \quad 0 < s < 3\Delta \qquad (4)$$

and $a_2$ is a polynomial constant. $\hat{DO}$ is the output of the polynomial filter, $DO_f$ is the output of the first order filter, and the $a_i$ values are chosen to minimize

$$\min_{a_0 \ldots a_3} \left[ \sum_{i=0}^{3} \left|\left| DO_f(t-i\Delta) - \hat{DO}(T-i\Delta) \right|\right| \right] \qquad (5)$$

The outputs of the polynomial filter are estimates of the DO level, its first and second derivatives. These are calculated from the quadratic approximation, as follows:

$$\hat{DO}_t = a_0 \qquad (a)$$

$$\dot{\hat{DO}}_t = \frac{d\hat{DO}}{dt} = a_1 \qquad (b) \quad (6)$$

$$\ddot{\hat{DO}}_t = \frac{d^2\hat{DO}}{dt^2} = 2a_2 \qquad (c)$$

The estimate for DO is then subtracted from the setpoint, SPT, to provide an error signal, $\hat{e}_t$

$$\hat{e}_t = SPT - \hat{DO}_t \qquad (7)$$

The estimates are input into the 'velocity' PI controller which is designed to compute the required change in the air flowrate, $\Delta Q_A$

$$\Delta Q_A = K(K_1 \dot{e} + K_2 e) \qquad (8)$$

$$= K(-K_1 \dot{\hat{DO}} + K_2 e)$$

where $\dot{e}$ = the first derivative of the error signal

$K_1$ = is the proportional band gain

$K_2$ = is the integral gain

The choice of tuning constants is made by evaluating the open-loop response of the DO to a step change in air flowrate, $Q_A$. The details are as follows. Assume the DO dynamics can be modelled as first order; then

$$\dot{DO} = \frac{dDO}{dt} = - \frac{1}{T} DO + \frac{K^*}{T} Q_A \qquad (9)$$

A regular PI control algorithm will have the form

$$Q_A = K'(K_1 e + K_2 \int e) \qquad (10)$$

Differentiating the DO and control equations, and substituting for $Q_A$, it is found that

$$\ddot{DO} = \frac{d^2DO}{dt^2} = \frac{1}{T} \dot{DO} + \frac{K^*}{T}(-K'[K_1 \dot{DO} + K_2(SPT-DO)) \qquad (11)$$

Collecting terms

$$\ddot{DO} + \left(\frac{1}{T} + \frac{K^*K'K_1}{T}\right)\dot{DO} + \frac{K_2K^*}{T} DO = \frac{K^*K_2}{T} SPT \qquad (12)$$

The dynamics of the closed loop DO-air flow rate system can then be specified. Usually a critically damped response is desired. There is considerable redundancy in the controller coefficients, and some can be assigned values a priori.

The velocity controller is derived from the PI controller as

$$\dot{u} = \frac{\Delta u}{\Delta t} = K'(K_1\dot{e} + K_2 e)$$

$$\Delta u = \underbrace{(K'\Delta t)}(-K_1\dot{DO} + K_2 e) \tag{13}$$

where K = overall gain, and u is velocity, and $\Delta t$ is the controller operating interval of approximately every 1 to 2 minutes for the DO system.

The final values for the controller gains were derived from on-line tuning after they had been originally set by assuming a 5 minute process-time constant. Setpoints used for the controller were 1.0 and 0.75 mg/l DO, with the first value used in the dry season experiments and the second for the wet season.

In actual operation of the controller, with commanded changes in air flowrate calculated every one or two minutes, excessive supervision and action would be required of the operator if every small command change was performed. Therefore, a dead band on control commands is incorporated in the controller to reduce the work load of small random control changes induced merely by residual measurement noise in the control signals.

The deadband is implemented by

$$\Delta u_c = \begin{cases} 0 & |\Delta u| \le \Delta u_{\text{deadband}} \\ \Delta u & |\Delta u| > \Delta u_{\text{deadband}} \end{cases} \tag{14}$$

Figure 6 is a block diagram of the complete DO control algorithm loop. The items within the dotted line are calculations performed by the computer. Various additional checks and procedures are incorporated in the real time control over and above the specific algorithm calculations to insure proper handling of various operating-environmental changes:

1. Controller will disable if valid measurements of DO and the current total air flow rate are not available.
2. Controller must be enabled manually once it has been disabled.
3. In the enabling process, the current DO measurement is used for the initial setpoint to assure a smooth transition from manual to automatic control. The set-point can subsequently be changed manually to the desired value.

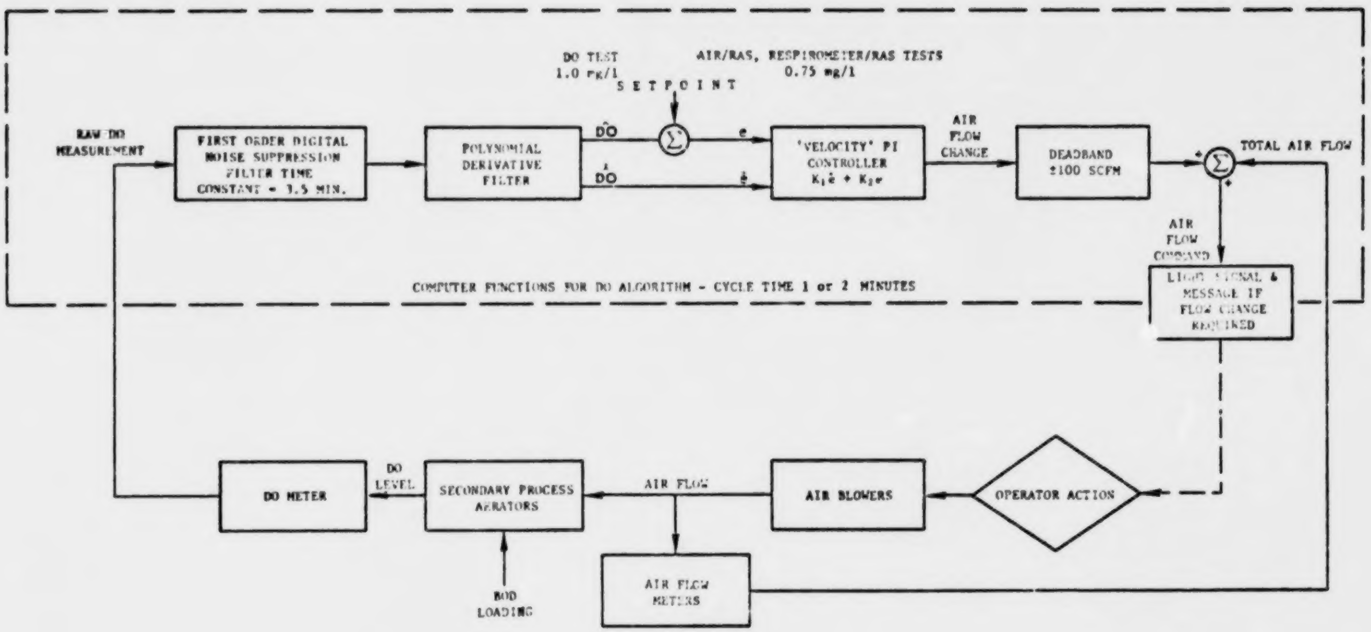
DO TEST
1.0 mg/1
AIR/RAS, RESPIROMETER/RAS TESTS
0.75 mg/1
SETPOINT
RAW DO
MEASUREMENT
FIRST ORDER DIGITAL
NOISE SUPPRESSION
FILTER TIME
CONSTANT = 3.5 MIN.
POLYNOMIAL
DERIVATIVE
FILTER
DO
DO
Σ
e
ė
'VELOCITY' PI
CONTROLLER
K₁ė + K₂e
AIR
FLOW
CHANGE
DEADBAND
±100 SCFM
Σ
TOTAL AIR FLOW
AIR
FLOW
COMMAND
LIGHT SIGNAL &
MESSAGE IF
FLOW CHANGE
REQUIRED
COMPUTER FUNCTIONS FOR DO ALGORITHM - CYCLE TIME 1 or 2 MINUTES
OPERATOR ACTION
AIR BLOWERS
AIR FLOW
AIR FLOW
METERS
SECONDARY PROCESS
AERATORS
BOD
LOADING
DO
LEVEL
DO METER

FIGURE 6. DISSOLVED OXYGEN CONTROLLER BLOCK DIAGRAM

A detailed flow chart of the complete controller algorithm and operating logic is given in Appendix A.

When the controller is functioning, the operator is alerted by an alarm light and is notified of a command change of specified size by the computer teletype. The light goes off on the next control cycle if no further command change is required.

## MLSS CONTROL

The secondary treatment aerator's MLSS controller was originally intended as a component in the various forms of F/M control based on food uptake. A setpoint for MLSS was selected, and the MLSS controller using a MLSS meter as the primary sensor then adjusted the return activated sludge to maintain the desired MLSS level. The contact stabilization configuration for plant operation was employed during this phase.

Contract stabilization treatment was, however, abandoned after the MLSS test period as a result of unsatisfactory plant operation.* The decision to return to conventional, completely mixed aeration with direct sludge recycle from secondary clarifiers was made by plant personnel with agreement of the EPA Cincinnati laboratory staff. Therefore, the MLSS controller (although designed, tested, and evaluated) was not utilized for its ultimate purpose. Results are still presented here, however, since they may prove useful if the plant operational problems are overcome or are not present at another facility.

The form of the MLSS control algorithm is completely analogous to the DO algorithm. The basis is, again, a standard proportional-plus-integral process controller. In this case, the measurement is MLSS. Solids concentrations are measured only in aerator 1, but this measurement is representative of all the aerators since they are fed from a common influent channel. The control mechanism is the RAS pumping rate which is controlled by operator adjustment of RAS pump speeds. First order, low-pass and polynomial filters are again used to condition the measurement. The velocity form of PI control is used, as well as the dead band on the calculated control-command output.

Tuning the MLSS controller follows the same procedure as for the DO control loop, except that the process time constant is on the order of four or five hours. Controller cycle time is set at 15 minutes. Operator notification of when an RAS flow rate change is needed is again accomplished by means of a light signal.

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*Excessive floating material thought to be dead microorganisms was observed in the secondary clarifiers. The sludge storage basin was thought to be the source of the problem since the problem largely disappeared as soon as the conventional mode of operation was reinstituted.

Figure 7 is a process schematic for MLSS control. Figure 8 is a block diagram of the MLSS algorithm computations. Real time checks and procedures similar to those used in the DO controller are also performed in the MLSS controller.

1. Valid measurement checks
2. Manual controller enabling
3. Smooth transition from manual to automatic operation.

A detailed flow chart of the complete controller algorithm and operating logic is given in Appendix A.

## AIR/RAS CONTROL

The objective of this study was to demonstrate a controlled F/M and to determine the effects of a controlled F/M on secondary treatment removal efficiency. Conventional manual operation maintains essentially a constant MLSS, and operates at an average F/M, based on daily average food and microorganism levels. In fact, however, plant loading varies quite significantly throughout the course of a day; thus, there are periods when the F/M value exceeds its average value. The three F/M oriented algorithms are:

- Air/RAS
- Respirometer/RAS
- TOC/RAS

In all three, RAS flow is used to adjust MLSS in order to keep F/M constant as the food utilization or aerator loading varies. The primary difference among the three controllers is in the means used to measure the food.

For the Air/RAS Controller, the air supplied to the completely mixed secondary treatment process is used as an indirect measure of biological respiration and therefore of the substrate (food) utilization, dF/dt. (See Appendix section B.2 for detailed development of the relation between air flow and substrate utilization).

$$\frac{dF}{dt} = c_1 Q_A + c_2 \qquad (15)$$

where $c_1$ = regression coefficient calculated using plant operating data

$c_2$ = regression coefficient calculated using plant operating data

$Q_A$ = air flow

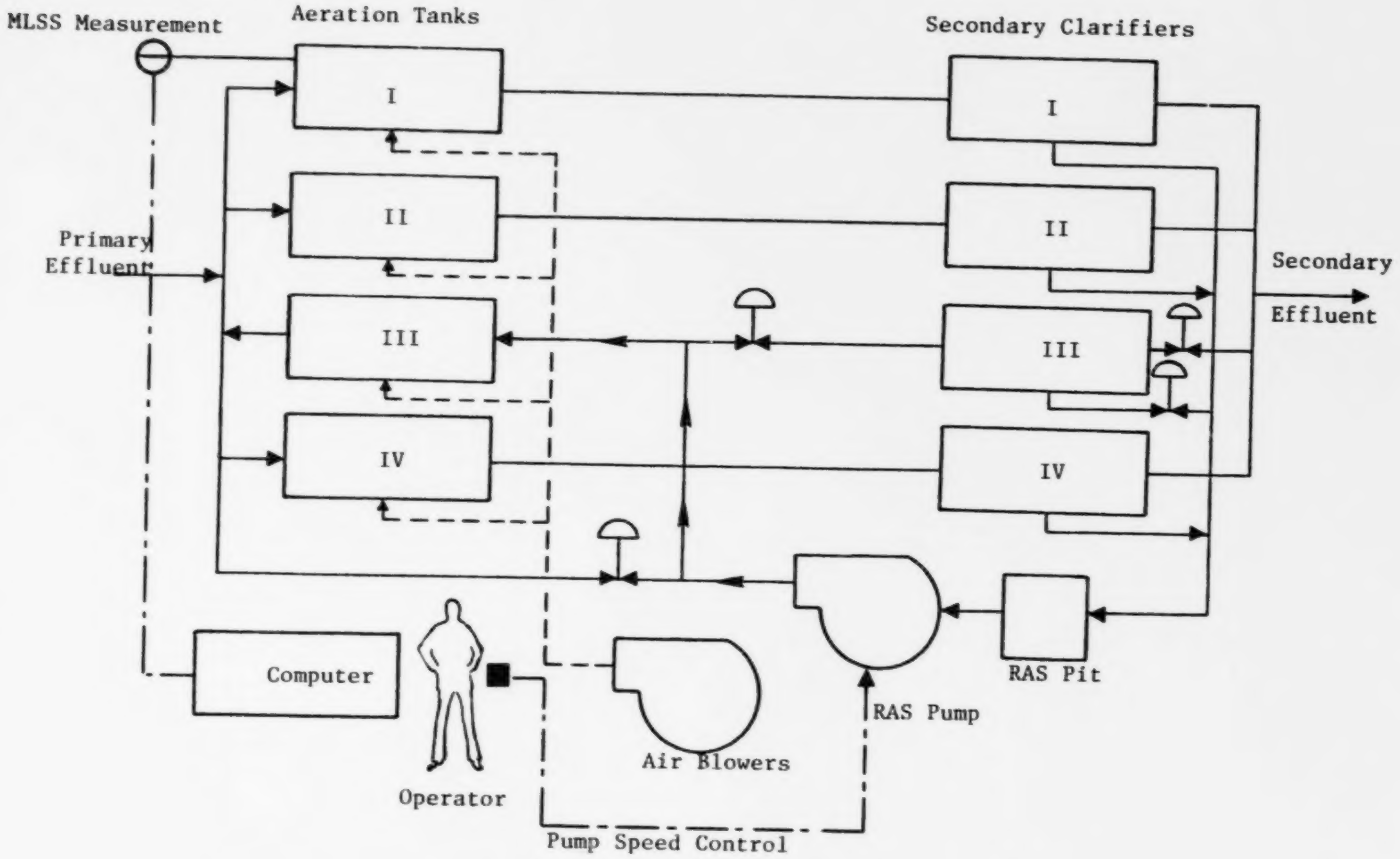

MLSS Measurement
Aeration Tanks
Secondary Clarifiers
I
II
III
IV
I
II
III
IV
Primary Effluent
Secondary Effluent
Computer
Operator
Air Blowers
RAS Pump
RAS Pit
Pump Speed Control

Figure 7. SCHEMATIC DIAGRAM OF THE MLSS CONTROL SYSTEM (ILLUSTRATED FOR CONTACT STABILIZATION MODE)

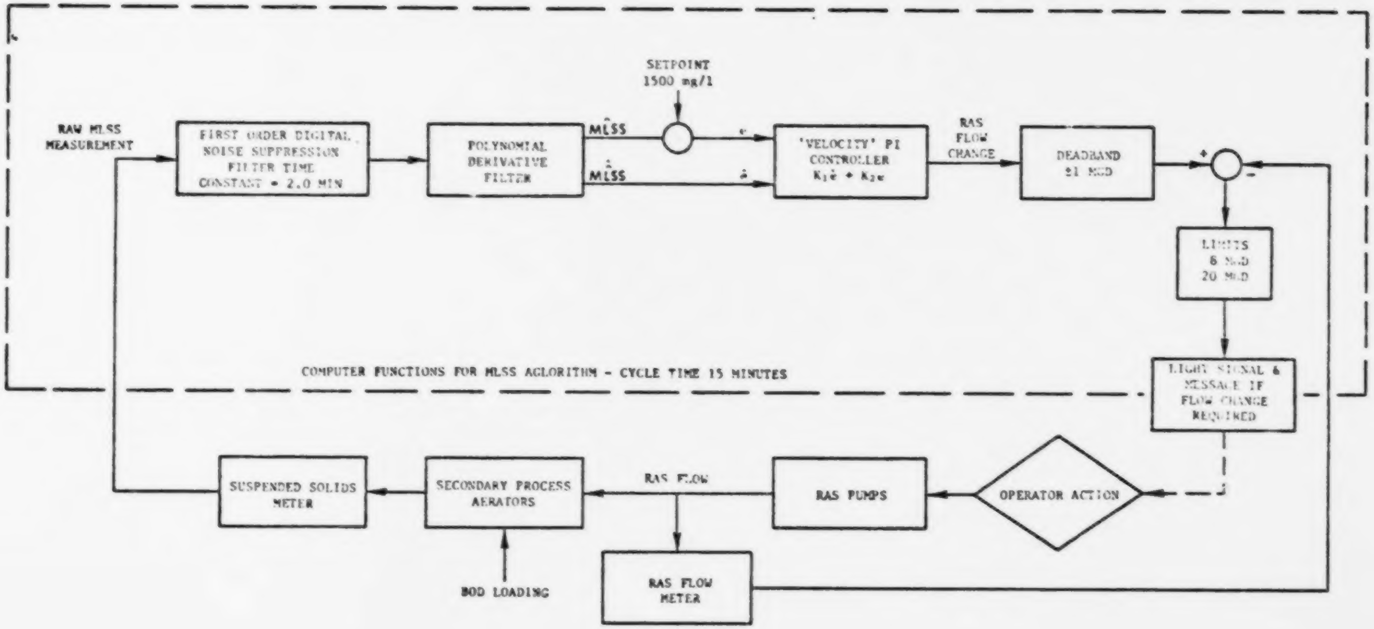

SETPOINT 1500 mg/l
RAW MLSS MEASUREMENT
FIRST ORDER DIGITAL NOISE SUPPRESSION FILTER TIME CONSTANT = 2.0 MIN
POLYNOMIAL DERIVATIVE FILTER
M̂LSS
M̂L̇SS
e
ė
'VELOCITY' PI CONTROLLER K₁ė + K₂e
RAS FLOW CHANGE
DEADBAND ±1 MGD
+
−
LIMITS 6 MGD 20 MGD
LIGHT SIGNAL & MESSAGE IF FLOW CHANGE REQUIRED
COMPUTER FUNCTIONS FOR MLSS AGLORITHM - CYCLE TIME 15 MINUTES
OPERATOR ACTION
RAS PUMPS
RAS FLOW
RAS FLOW METER
SECONDARY PROCESS AERATORS
BOD LOADING
SUSPENDED SOLIDS METER

FIGURE 8. MLSS CONTROLLER BLOCK DIAGRAM

With the desired F/M, the MLSS level necessary to achieve that ratio can be calculated. The RAS flow is then adjusted to bring the actual MLSS to the desired value.

Originally, it was intended that the MLSS controller would be used in cascade to bring about the desired changes in MLSS. The setpoint to the MLSS controller would be the required solids level for a constant F/M ratio, as calculated by the Air/RAS controller. As previously discussed however, the MLSS controller is incompatible with the plant in the completely mixed mode of operation during the F/M ratio controller tests. The incompatibility is caused by the fact that the wasting rate and MLSS concentration are not independent. Appendix section B.4 contains the derivation of the relation between F/M, U, and the mean cell residence time, $\theta_c$, which could be used to set the sludge waste rate:

$$U = \frac{dF/dt}{XV_a} = \left[ \frac{f_v}{Y} \; \frac{V_a + V_c}{V_a \theta_c} + K_d \right] \qquad (16)$$

where $K_d$ is the endogenous respiration rate constant, Y is the yield coefficient and $f_v$ is the ratio of the volatile to the total suspended solids. However, the dynamic biological model constants $K_d$, Y, and $f_v$ are subject to considerable variability and $\theta_c$ is not known precisely, so that U is subject to variability.

Therefore, the MLSS controller was not used in cascade with the various forms of F/M control. Instead, the RAS flow was set based on what the MLSS solids level should be in a steady state operation. This procedure ignored the concentration lag inherent in the aerator tanks' retention time, so there was some delay between changes in the actual MLSS and the commanded value. The advantage of the steady state operation approach is, however, a self-regulating characteristic with regard to the average F/M and the final clarifier sludge level.

The algorithm for determining the RAS flow, $Q_{R_c}$, is

$$Q_{R_c} = \frac{Q}{\frac{X_R}{X_c} + 1} \qquad (17)$$

and a detailed derivation of the algorithm, based on mass steady state balances around the aerators, is given in Appendix B.1. $X_R$ is the average RAS suspended solids concentration obtained from plant laboratory-monitoring analyses and is assumed constant. The desired MLSS setpoint, $X_c$, is derived from Equations 15 and 16.

$$X_c = \frac{dF/dt}{UV_a} = \frac{[c_1 Q_A + c_2]}{U\ V_a} \qquad (18)$$

The self regulatory or smoothing feature of this algorithm, with respect to average MLSS level and clarifier sludge level, occurs because of the assumed constant, $X_R$. In actuality, average $X_R$ varies in proportion to the average sludge level in the clarifiers. This means that the average solids returned, $Q_R\ X_R$, will go up when the clarifier sludge level goes up since $Q_R$ (average value) remains relatively constant; this phenomenon automatically regulates the clarifier sludge level. A similar smoothing effect is also produced in the aerators where a constant volume of mixed liquor wasted to the thickener automatically regulates variations in the average MLSS concentration.

Implementation of the Air/RAS control algorithm embodied in Equations 17 and 18 requires measurement of total air flow, $Q_A$, plant flow, Q, and RAS flow, $Q_R$. Fortuitously, the measurement of plant flow is at the plant headworks and a thirty minute lag in flow was observed across its primary plant; a feedforward lead of about 30 minutes is incorporated in the algorithm, compensating to some extent for the previously discussed lag inherent in the algorithm.

Figure 9 is a schematic of the F/M control plan. An algorithm block diagram of the Air/RAS form of F/M control is given in Figure 10.

Additional, real time, operation-oriented features of the controller include:

- Deadband on commanded RAS changes
- Measurement validity checks
- RAS command limits
- RAS-pump, suction-pit level control

The controller commands are carried out as described for the MLSS controller with signal-light notification to the operator to change RAS flows by adjusting RAS pump speeds. Deadband is therefore incorporated to avoid frequent, low-level, command changes. Measurement validity is checked every 30 minutes when the controller cycles.

RAS command limits are incorporated primarily for low flow conditions. Insufficient RAS flow (below between 6 to 8 MGD(.023 to .030 $Mm^3$/day)) causes plugging of the clarifier decanting lines. A procedure necessary to enable even that low-flow limit involves manually choking down the butterfly valves of its clarifier draw-off lines below 10 (.038 $Mm^3$/day) MGD RAS flow. This procedure keeps the RAS-pit level low enough to maintain sufficient head on the decanting lines to prevent plugging.

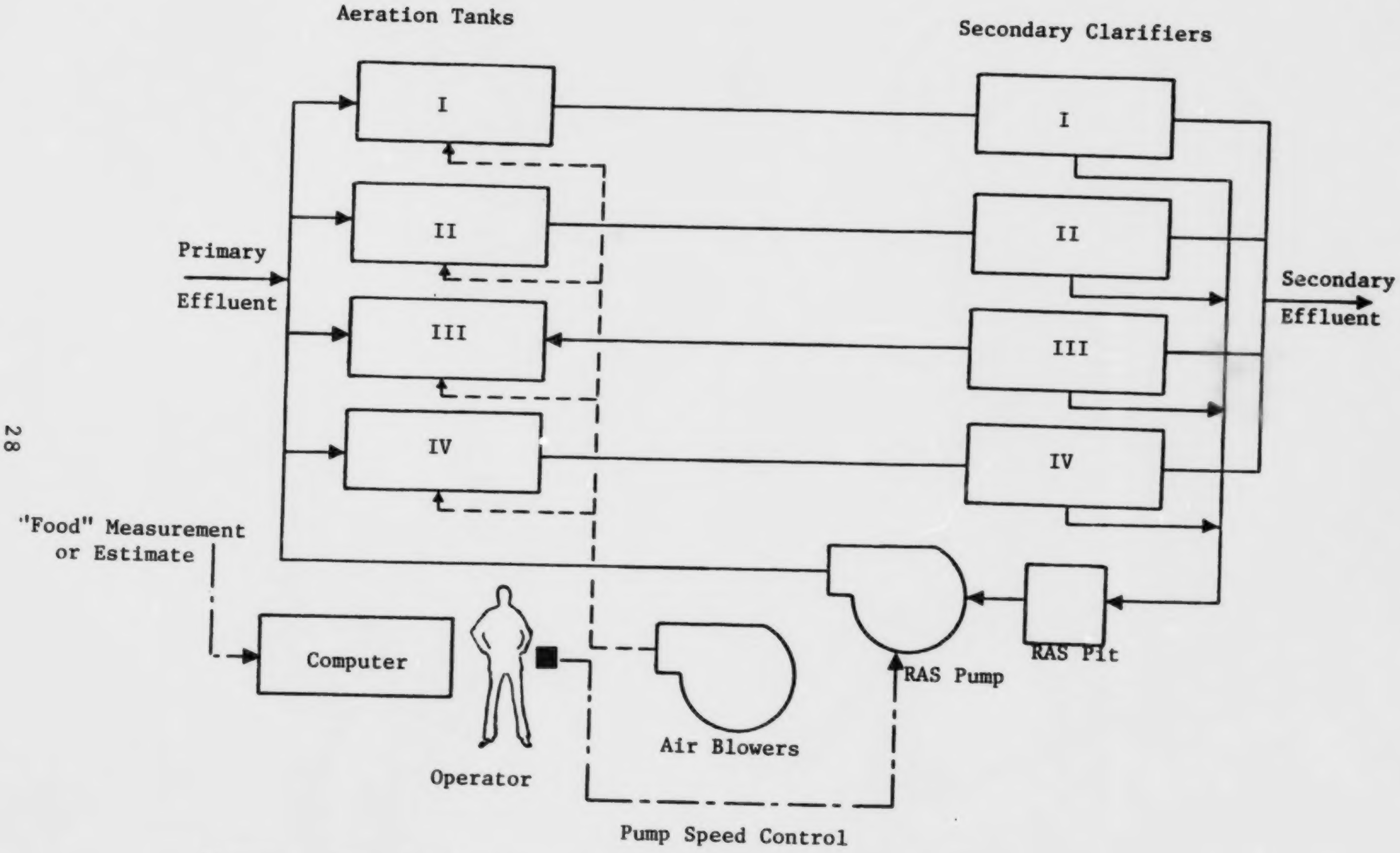

Aeration Tanks
Secondary Clarifiers
I
II
III
IV
I
II
III
IV
Primary Effluent
Secondary Effluent
"Food" Measurement or Estimate
Computer
Operator
Air Blowers
RAS Pump
RAS Pit
Pump Speed Control

Figure 9. SCHEMATIC DIAGRAM OF FOOD TO MICROORGANISM RATIO CONTROL SYSTEMS (ILLUSTRATED FOR CONVENTIONAL MODE)

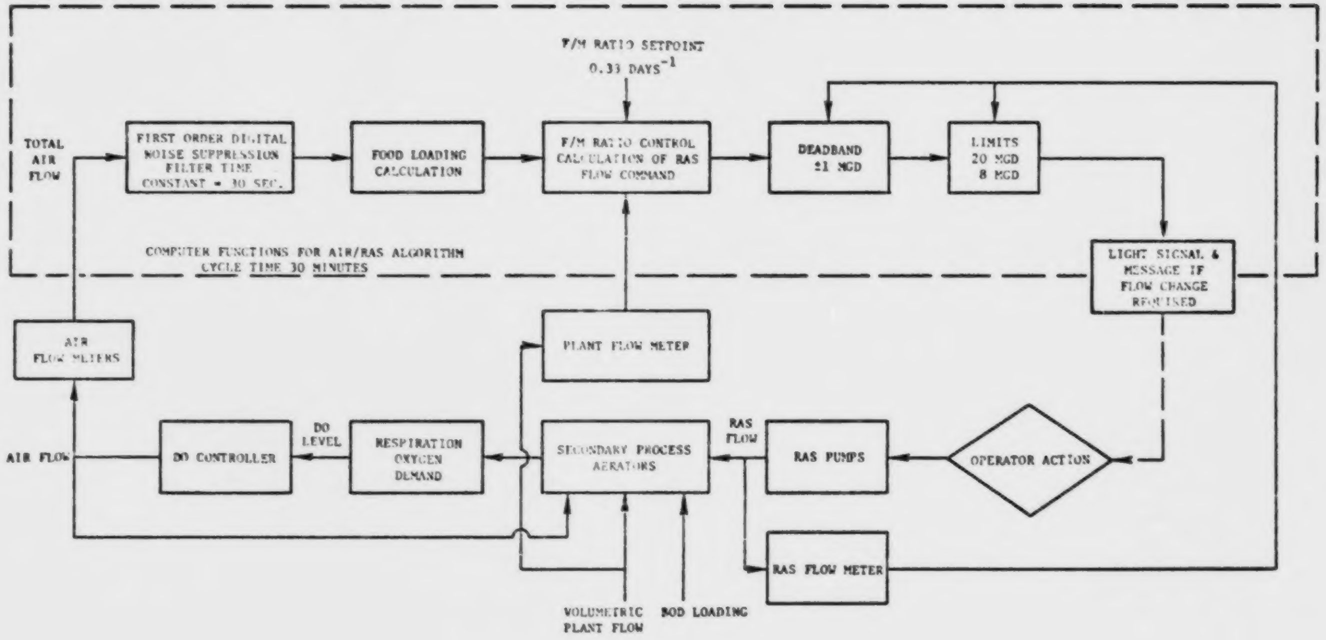

F/M RATIO SETPOINT
0.33 DAYS$^{-1}$
TOTAL AIR FLOW
FIRST ORDER DIGITAL NOISE SUPPRESSION FILTER TIME CONSTANT = 30 SEC.
FOOD LOADING CALCULATION
F/M RATIO CONTROL CALCULATION OF RAS FLOW COMMAND
DEADBAND ±1 MGD
LIMITS 20 MGD 8 MGD
COMPUTER FUNCTIONS FOR AIR/RAS ALGORITHM CYCLE TIME 30 MINUTES
LIGHT SIGNAL & MESSAGE IF FLOW CHANGE REQUIRED
AIR FLOW METERS
PLANT FLOW METER
AIR FLOW
DO CONTROLLER
DO LEVEL
RESPIRATION OXYGEN DEMAND
SECONDARY PROCESS AERATORS
RAS FLOW
RAS PUMPS
OPERATOR ACTION
RAS FLOW METER
VOLUMETRIC PLANT FLOW
BOD LOADING

FIGURE 10. AIR/RAS CONTROLLER BLOCK DIAGRAM

The algorithm monitors RAS flow commands and types a message for the operator when a change in valve positions is required.

## RESPIROMETER/RAS CONTROL

This algorithm is completely analogous to the Air/RAS controller in that the intent is to maintain a constant F/M value in the secondary aerators. The major difference is in the instrumentation employed to determine the food uptake rate.

Both controllers estimate food uptake from microorganism respiration. Whereas the Air/RAS form uses the air supplied to the aerators as a measure of respiration, the Respirometer/RAS incorporated the Badger Meter Company's "Biological Respirometer" for direct indication of respiration from a sample of mixed liquor. The following relationship between measured respiration rate per unit volume, R, and food uptake is developed for the Badger Respirometer in Appendix section B.5:

$$\frac{dF}{dt} = V_a \left( \frac{R - K_d X}{1.0 - YyL} \right) \tag{19}$$

where $V_a$ is the volume of the aerators. In the Palo Alto plant, values for the parameters in Equation 2.9 are estimated as

$$K_d = 0.05 \text{ days}^{-1}, \quad X \sim 1200 \text{ mg/l},$$

$$Y = 0.5, \quad y = 1.42, \quad L = 0.5$$

so that in the algorithm calculation

$$\frac{dF}{dt} = \frac{1}{.745} \left[ R - 2.5 \right] \text{ mg/l hr} \tag{20}$$

Typical readings for R average around 24 mg/l hr.

The Respirometer/RAS algorithm calculations therefore employ the expression for dF/(dt) of Equation 20 in Equations 17 and 18 to determine the RAS flow commands. A block diagram of the controller is given in Figure 11 and is seen to be exactly the same as the Air/RAS, except for the replacement of the air flow measurement by the respirometer measurement. Additional real time checks and procedures common to all the F/M controller are also included:

- Deadband on commanded RAS changes
- Valid measurement checks

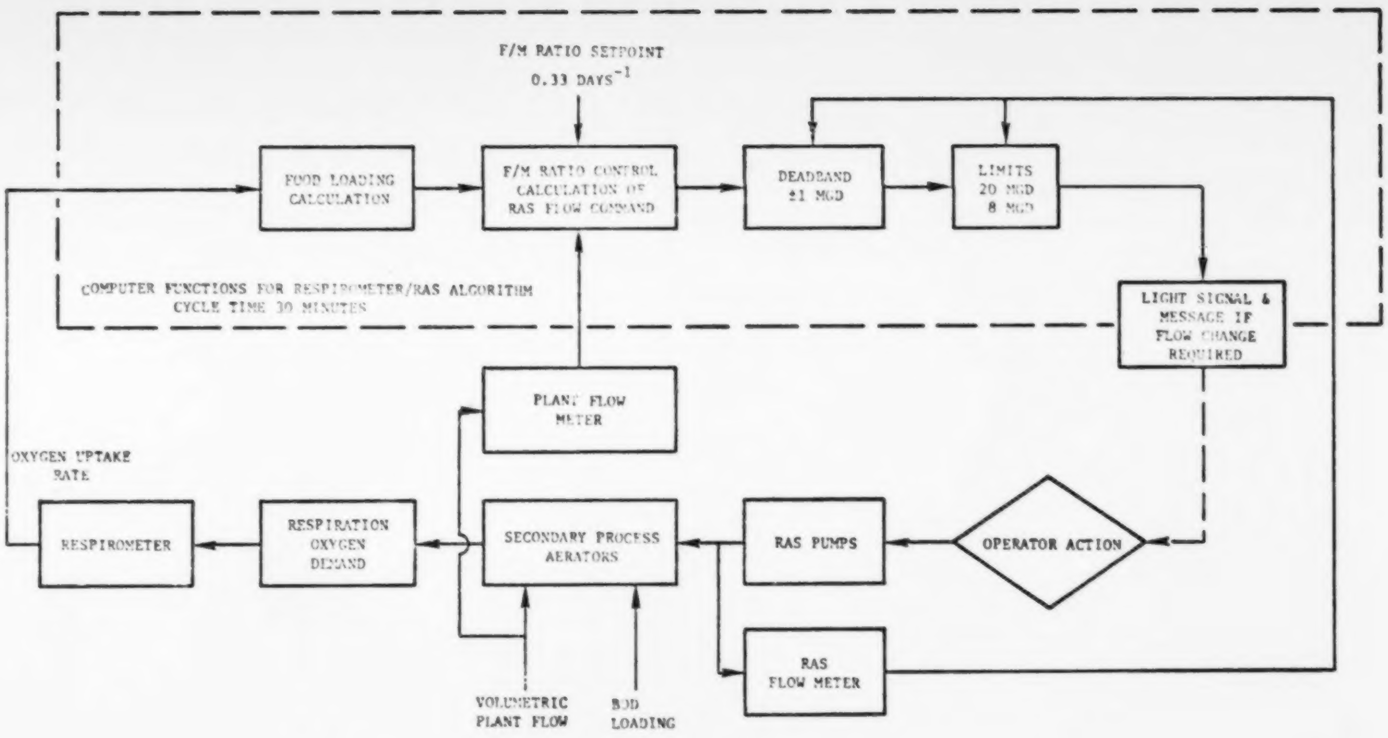

F/M RATIO SETPOINT
0.33 DAYS$^{-1}$
FOOD LOADING CALCULATION
F/M RATIO CONTROL CALCULATION OF RAS FLOW COMMAND
DEADBAND ±1 MGD
LIMITS 20 MGD 8 MGD
COMPUTER FUNCTIONS FOR RESPIROMETER/RAS ALGORITHM CYCLE TIME 30 MINUTES
LIGHT SIGNAL & MESSAGE IF FLOW CHANGE REQUIRED
PLANT FLOW METER
OXYGEN UPTAKE RATE
RESPIROMETER
RESPIRATION OXYGEN DEMAND
SECONDARY PROCESS AERATORS
RAS PUMPS
OPERATOR ACTION
RAS FLOW METER
VOLUMETRIC PLANT FLOW
BOD LOADING

FIGURE 11. RESPIROMETER/RAS CONTROLLER BLOCK DIAGRAM

- RAS command limits
- RAS-pump suction-pit level control

Operator procedures for implementation of command changes is the same as for the Air/RAS controller.

## TOC/RAS CONTROLLER

Appendix B.3 details the relationship between secondary treatment loading (food-inflow rate) and biological food utilization. The development shows that there is a lag equivalent to a first order time constant of approximately 10 minutes between food influx and subsequent utilization. For the Respirometer/RAS controller, there is an additional measurement lag of 1 hour in the Respirometer operation. With the Air/RAS, there is a delay of 10 to 20 minutes in the response of the air flow measure of respiration due to lags inherent in the DO controller which adjusts the actual air supply rate. Altogether then, there is a lag in the first two forms of F/M control of anywhere from 20 to 70 minutes between aerator loading changes and actual measurement of the new loading for control purposes.

The intent of the TOC/RAS controller is to avoid these long, food loading, measurement lags and thus improve the response capability of F/M control. This was to be accomplished by an on-line measurement of TOC in the secondary influent. A relationship between instrument TOC measurements and laboratory $BOD_5$ measurement in the influent, was to be determined, and then a measurement of the incoming load could be calculated as $QS_o$.

With the $QS_o$ measurement substituted for dF/(dt) in Equation 19, a feedforward MLSS command for F/M control is produced. The expectation was that this feedforward TOC/RAS control would yield a better regulation of F/M by compensating more fully for the measurement lags discussed above and partially for the aerator retention-time lag mentioned previously.

Other features of the TOC/RAS control algorithm are the same as described for the Air/RAS and Respirometer/RAS controllers. Commanded changes in RAS pumping rates were also to be performed in the same manner as for the other F/M controllers. A block diagram of the TOC/RAS control-algorithm design is given in Figure 12.

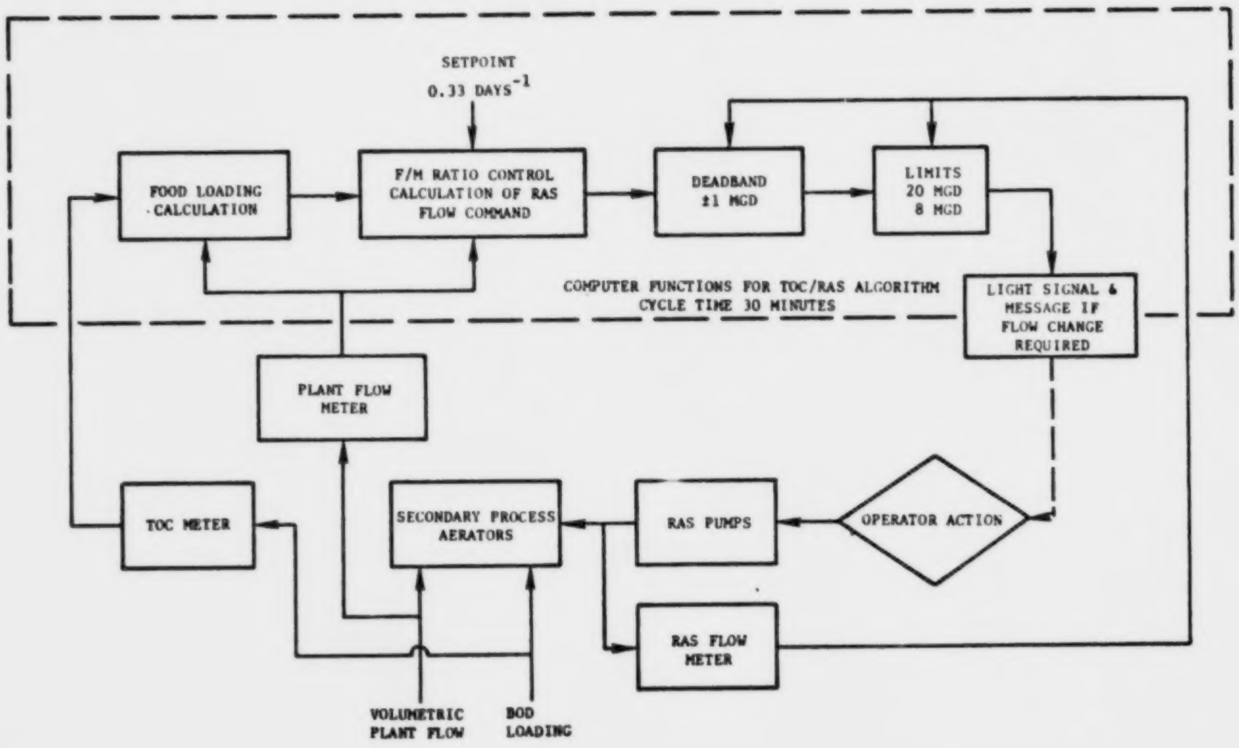

SETPOINT
0.33 DAYS$^{-1}$
FOOD LOADING CALCULATION
F/M RATIO CONTROL CALCULATION OF RAS FLOW COMMAND
DEADBAND ±1 MGD
LIMITS 20 MGD 8 MGD
COMPUTER FUNCTIONS FOR TOC/RAS ALGORITHM CYCLE TIME 30 MINUTES
LIGHT SIGNAL & MESSAGE IF FLOW CHANGE REQUIRED
PLANT FLOW METER
OPERATOR ACTION
TOC METER
SECONDARY PROCESS AERATORS
RAS PUMPS
RAS FLOW METER
VOLUMETRIC PLANT FLOW
BOD LOADING

FIGURE 12 TOC/RAS FEEDFORWARD CONTROLLER BLOCK DIAGRAM

# SECTION VI

# EXPERIMENTAL DESIGN

## SCOPE

This section disucsses the experimental plan for accurate comparisons of performance and cost effectiveness of the manually and computer controlled operation of the Palo Alto Wastewater Treatment Facility. The plan defines the data gathering and analysis requirements, as well as the plant operation requirements for each of the phases of the program. Included are details on where each sample was collected, how it was collected, the type of analysis that was performed on the samples in the laboratory as well as the format of data that was inserted into the digital computer.

In formulating the experimental design plan, care was exercised to provide several features which would ensure the validity and utility of the results. These features include:

- Accurate benchmark of the manually operated process by establishing an operating procedure consistent with average operating procedures of manually controlled wastewater treatment plants within the State of California.
- Provision for long-term relative evaluation of each of the control systems in terms of ability to enhance the quality of discharges as well as reduce operating costs.
- Provision for short-term detailed evaluation and analysis of the plant under both manual and automatic control over the complete dynamic range of operation. This will lead to a more complete understanding of the process itself, as well as a quantitative evaluation of performance parameters associated with the control modes.
- Allowance for potential stress on each control system to allow a complete evaluation under normal and abnormal operating conditions.

Specifically, this section describes the general method of testing and an associated time-phased schedule; the manually controlled portion of the test in terms of both the operating procedures to be employed and the data gathering techniques; the automatic control portion of the experiments, again in terms of the operating procedures and data collection methods; and, finally the types of data analysis performed on the collected data base.

## EVALUATION PLAN

In order to obtain a performance and cost effective evaluation of the comparison of the plant operating under manual and automatic control, a methodology was established which provided an adequate amount of accurate data concerning the process. The general experimental plan that was used to meet these objectives is outlined in the steps below:

Step 1 - For an initial period of approximately four weeks, the contact stabilization process was controlled manually according to procedures which represent average control of water treatment plants within the State of California (e.g., air-blowing rate was adjusted twice daily). This served as a process benchmark for future automatic control modes. During this period of manual control, data collection and analysis was divided into two phases; a non-intensive phase and an intensive phase. The non-intensive phase of data collection and analysis lasted for approximately three and one-half weeks and was oriented toward obtaining average plant-performance characteristics over an extended time period. Data collected, for example, provided the average, daily, $BOD_5$ reduction over the period. In addition during this phase, some data, such as suspended solids levels and DO profiles in the aerators, was collected at relatively high frequencies-nominally every two hours. This verified that the plant was operating as designed and that instruments were operating properly and were properly calibrated. The intensive period of data collection spanned a three-day period which represented both the extreme operating conditions of the plant, as well as an average operating condition. The days selected for intensive data collection were Sunday (which represents an abnormally low, flow profile during the day, as well as a different flow pattern from the remaining six week days), Monday (which represents the peak flow condition and most stressing situation for the plant) and Tuesday (which represents an average, daily, flow condition and profile). During this period, all relevant plant-performance data was collected and analyzed on a two-hour basis to provide detailed information concerning the dynamics of the plant (e.g., daily $BOD_5$, TOC and COD profiles at two-hour intervals at points within the plant). This information was then utilized for both the subsequent detailed comparative analysis of the control modes, in addition to providing detailed information concerning the characteristics of the plant. Details concerning the exact location and frequency of data collection and analysis is provided later.

Step 2 - At the completion of the intensive data-collection phase of manual operation, the first automatic control system (DO control) was activated using the contact stabilization configuration. The DO control system was operated for approximately four weeks to provide (a) sufficient time for transients associated with the change in control strategy to decay and for the plant to assume steady state operation and (b) a large enough data base to perform meaningful comparative evaluation of average plant performance. Data collection and analysis consisted of a non-intensive phase of approximately three and one-half weeks followed by an intensive phase on the concluding Sunday, Monday and Tuesday. Data collection and analysis was identical to the manual control period with the exception that, in addition to plant performance data, only sufficient samples of parameters, (such as DO level in each of the tanks) required to calibrate sensors were taken during the non-intensive phase.

Step 3 - The next control scheme (MLSS) was evaluated by operating its plant as in Step 2 above with the contact stabilization configuration.

Step 4 - The Air/RAS control scheme was evaluated by operating the plant under the complete mix configuration.

Step 5 - After installation of the TOC analyzer and the respirometer, the Respirometer/RAS control system was evaluated in a manner identical to the procedure given in Step 4 above. Because of difficulties with the TOC analyzer this control strategy was not implemented.

It was felt that the above methodology represented a cost and time effective experimental procedure for the comparative evaluation of the control strategies. It provided for collection and comparison of adequate amounts of data to monitor and compare the process over ranges of operation in a cost effective manner.

## MANUAL CONTROL PROCEDURES

The automatic control procedures and algorithms have been described previously. But in order to accurately compare performance and cost of the automatic control systems, it was important that the manual operation of the plant be standardized during the evaluation phase. As described below, the major operating procedures employed at the plant during manual control had been derived from analyses of typical operations of wastewater treatment facilities of comparable size and operation in the State of California. It should be carefully noted, however, that the control policy described below represents a typical method of activated sludge process control; i.e., the procedure is deemed average and is not to be taken as representative of what could be done at Palo Alto. The intent was to determine the average efficiency of Palo Alto's secondary system when operated under a conventional manual control strategy.

The major control operations influencing the secondary process are the air flowrate into the aeration tank, the return activated sludge flowrate into the sludge storage tank and the mixed liquor wasting rate. The control strategy for each of these elements is described below.

The air flowrate to the aerators was adjusted twice daily during manual operation. At 0900 hours each day, the No. 1 and No. 3 blowers were set at full speed, and No. 5 blower set at its minimum speed (for peak flow conditions). There were no changes in the individual tank valve settings.

At 2200 hours each day No. 3 blower was set to its minimum speed and No. 5 blower was shut down. The No. 1 blower remained at full speed for the entire test period.

| Summary |  | Blower |  |  |
|---|---|---|---|---|
| Control | Time | #1 | #3 | #5 |
| High Speed | 0900 hours | Full | Full | Min. |
| Low Speed | 2200 hours | Full | Min. | Off |

It is noted that during all phases of both manual and automatic control operation, the butterfly valves between the blower and the aerators remained fixed.

The RAS flowrate was adjusted once per day during manual operation. This rate was computed each day at 1300 hours based on the 30-minute settled volume. The return rate for the next 24 hours was determined by the formula:

$$Q_R = \frac{Q \cdot (\text{set. vol.})}{1000 - (\text{set. vol.})}$$

where $Q_R$ = return activated sludge flowrate (MGD),

$Q$ = plant flowrate (MGD)

set. vol. = 30-minute settled volume (ml)

For the following (representative) conditions,

30 Minute Settling Test = 250 ml

Expected Plant Flowrate = 25 MGD = Q

the calculation would be

$$Q_R = (25)\ (250)/(1000-250) = 8.33 \text{ MGD } (.032 \text{ Mm}^3/\text{day})$$

The return activated sludge pump speed was then set to return activated sludge at a flowrate of 8.33 MGD (0.032 $\text{Mm}^3$/ day). No adjustments in the return rate were made until the next day at 1300 hours.

The above procedure was adopted based on the consideration that the peak flows occur at approximately 1300 hours and that acceptably representative averages (i.e., 30 minute settling) could be obtained at that time. This method has been used successfully at the plant to this date.

As in completely mixed operation, the wasting rate during operation in the modified contact stabilization configuration was adjusted once daily during the manual operation. This rate was that required to maintain a mean cell residence time of 10 days and was adjusted each day at 1300 hours. The wasting pump speeds were adjusted to maintain a constant waste mixed liquor flowrate for the next 24 hours. Wasting was accomplished by wasting mixed liquor directly from areator #1. The waste mixed liquor flowrate was computed as follows:

$$Q_{WML}(\#1) = \frac{(5.61)(MLSS_{AVE}) + (1.87)(MLSS\ \#2) - (\theta_c)(Q)(SE_{ss})}{(MLSS\ \#1 - SE_{ss}\ \theta_c)}$$

where $SE_{ss}$ = secondary effluent suspended solids (mg/l)

$MLSS\#x$ = suspended solids in aerator #x (mg/l)

$$MLSS_{AVE} = \frac{MLSS\ \#1 + MLSS\ \#3 + MLSS\ \#4}{3}\ (mg/l)$$

$\theta_c$ = mean cell retention time (days)

$Q$ = average plant flowrate (MGD)

$Q_{WML}$ = waste mixed liquor flowrate (MGD)

For the representative parameters given below, the calculation becomes:

MLSS #1 = 2618 mg/l

MLSS #3 = 1926 mg/l

MLSS #4 = 1875 mg/l

$$MLSS_{AVE} = \frac{2618 + 1926 + 1875}{3} = 2139.6\ mg/l$$

$Q$ = 25.0 MGD (.095 $Mm^3$/day)

MLSS #2 = 6136 mg/l (sludge storage)

$$Q_{WML}\ \#1 = \frac{(5.61)(2139.6) + (1.87)(6136) - (10)(25)(30)}{(2618 - 30)(10)}$$

$$= 0.617\ MGD\ (.0023\ Mm^3/day)$$

Note that this flowrate is the actual waste-mixed-liquor flowrate from the #1 aerator. To set the actual waste rate, all secondary effluent pumps were shut down, and the WML pump speed was adjusted to obtain the desired flowrate ($Q_{WML}$).

Daily Sample Collection and Analysis Period (Non-intensive)

During the non-intensive phase of the initial manual-control period, a substantial number of samples were collected and analyzed. This was done to assure that the plant was functioning properly and that all instruments were calibrated and operating correctly. In addition, the sampling was compatible with a dry run of the intensive sample-collection and analysis phase at the conclusion of the manual control period. Similar sampling was performed during the control studies but not necessarily at the same sample frequency.

The location and method of sample collection is extremely critical to obtain representative laboratory results. Therefore, it was essential that an adequate and uniform procedure be used in collecting samples. All samples were taken by the following procedures, using quart bottles to obtain adequate samples.

Raw Sewage - The sample was taken from the primary influent channel. The first hatch cover (before the thickeners) was removed, and the sample was collected at a depth of 2 - 4 feet (0.6 - 1.2 m).

Primary Effluent - In order to obtain a representative sample of primary effluent, a composite was formed. The composite grab sample was generated by mixing equal volumes from the effluent launders of those primary clarifiers in service.

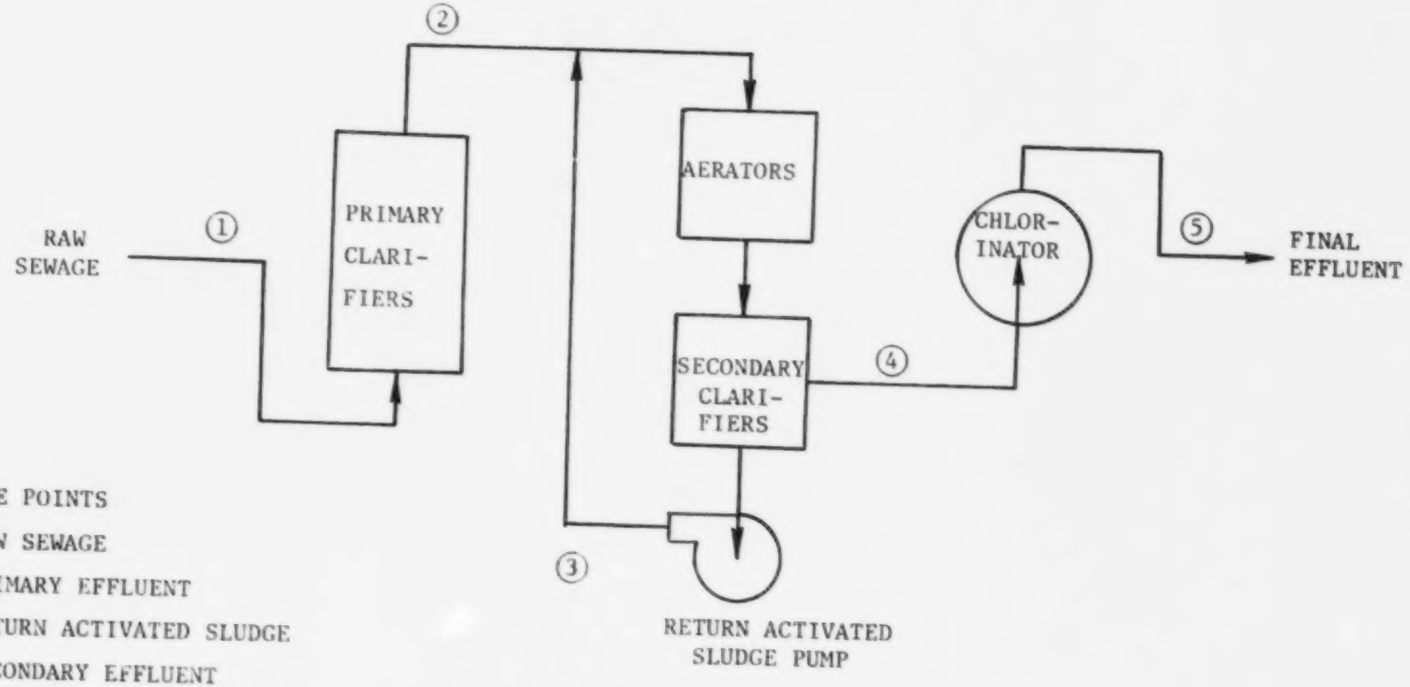
Secondary Effluent - A grab sample of secondary effluent was obtained from the line connected to the 60 inch (1.5 m) secondary effluent line. This line is downstream of the clarifiers and is itself a composited sample of secondary effluent.

Final Effluent (after chlorination) - A grab sample from the effluent junction box was taken. This sample was taken at a depth of 2 feet (1.2 m) to ensure mixing.

Mixed Liquor - A separate sample from each of the three aerators was taken. The samples were collected at the following locations (see Figure 13) platforms #1B, #3C, #4A at a depth of 2 - 4 feet (0.6 - 1.2 m). These sample locations were selected since they are the farthest locations from the mixed liquor in flows. The samples were taken for the purpose of DO probe and MLSS meter calibration. During conventional operation, an addition sample was taken from aerator 2, at platform 2A.

Return Activated Sludge - A grab sample from #2A aeration platform (sludge aeration tank) was taken at a depth of 2 - 4 feet (0.6 - 1.2 m). During conventional operation the sample was taken from the RAS pit.

For the initial non-intensive manual operation phase, all samples indicated above were collected daily on the even hours (i.e. 00,.02,..., 2200 hours) and composited on a 24 hour basis. During the period of automatic operation the primary effluent, secondary effluent, final effluent, mixed liquor and return activated sludge were sampled three times a day nominally in the midpoint of each shift.


RAW
SEWAGE
①
PRIMARY
CLARI-
FIERS
②
AERATORS
SECONDARY
CLARI-
FIERS
③
RETURN ACTIVATED
SLUDGE PUMP
④
CHLOR-
INATOR
⑤
FINAL
EFFLUENT

SAMPLE POINTS

1. RAW SEWAGE
2. PRIMARY EFFLUENT
3. RETURN ACTIVATED SLUDGE
4. SECONDARY EFFLUENT
5. FINAL EFFLUENT

SCHEMATIC DIAGRAM OF THE PLANT
WITH PROCESS SAMPLE POINTS INDICATED
FIGURE 13

During this period, the raw sewage, primary effluent, secondary effluent, and final effluent were analyzed every 2 hours for pH. These samples were then composited throughout the day and analyzed the following day. The composited sample was also analyzed for suspended solids, $BOD_5$, TOC, COD, $NH_3$, $NO_2$, $NO_3$, and ortho phosphates.

In all cases the collected samples were analyzed according to accepted methods. Where possible, methods indicated in Reference (3), "Standard Methods for the Examination of Water and Waste Water," were utilized. Specifically, the sample analyses for the quantities of interest were as indicated in Table 1.

Table 1. ANALYTICAL TECHNIQUES

| Quantity Desired | Sample Analysis Technique |
|---|---|
| Suspended Solids | Gravimetric Method |
| $BOD_5$ | Winkler Method - Azide Modification |
| COD | Potassium Dichromate Oxidation |
| TOC | TOC Analyzer (Envirotech) |
| $NH_3$ | Specific Ion Electrode |
| $NO_3$ | Photometry |
| $NO_2$ | Photometry |
| Ortho Phosphates | Photometry |
| pH | Electrometric |
| 30 Minute Settling | Standard Method |
| Sludge Volume Index (SVI) | $\left(\frac{\text{30 min. settling vol. in aerator}}{\text{suspended solids in aerator}}\right) \times 1000$ |

Bihourly - Data Collection and Analysis Period (Intensive)

The data collection and analysis performed during the intensive sampling of the initial manual-control period was intended to provide: (1) detailed information regarding the processes within the plant, and (2) a data base for detailed comparison of the control system effectiveness. The data gathered during this phase was used to generate the important statistical-performance parameters for the analysis phase of the study. Similar intensive sampling was also performed during the control studies.

The samples were collected from those locations described previously. Twelve samples were collected daily, on the even hours. In addition, during the automatic control operation and for the five-day period prior to the Sunday, Monday or Tuesday intensive data collection, the mixed liquor and return sludge were sampled four times during the day shift for the purpose of calibration of sensors and monitoring their performance.

Sample collection analysis was as indicated previously with the exception that the bi-hourly samples were not composited. That is, each sample was analyzed for suspended solids, $BOD_5$, TOC, COD, $NH_3$, $NO_2$, $NO_3$, and ortho phosphates. Hence, a complete set of thirty-six data points over the three day period were available for analysis.

## DATA ANALYSIS

Data base variables consisted of two types: on-line process data and laboratory data. Process data was recorded automatically by the System/7 on-line every six seconds. At two-minute intervals, data was transferred to the disc storage. On a once-per-day basis this data was recorded on magnetic tape for subsequent analysis. A list of the process variables recorded is given in Table 2.

Laboratory data was entered into the on-site System/7 through the use of the LAB program. This program accepted data via the teletype for any hour of the day within the preceding 15 days. Normally, all laboratory data from a given day was not available for 5 days (due to the 5 day $BOD_5$ period), and the 15-day period allowed for weekends and other potential delays. Again, data was transferred from the System/7 to magnetic tape for subsequent analysis. Table 3 contains a list of the laboratory data recorded.

A brief description of the data analysis techniques that were utilized to perform the comparative analysis of the performance of control schemes is given on page 45.

Basically, the data analysis consisted of: (1) performance and cost comparison over the full 28-day period utilizing, the averaged and composited daily data, and (2) detailed performance and cost comparison over the three-day intensive period, utilizing bi-hourly process and lab data.

Appendix C contains the data for the manual control period in the form in which it was used for the comparative analysis studies. As illustrated in the Appendix, the data base was used to compute the following:

1. Daily data for each of the 28-days of the particular control phase. This was later utilized to compare the average performance of the schemes during the period. As illustrated,

### Table 2. PROCESS DATA

| Description | Units |
|---|---|
| Total plant flow | mgd |
| Los Altos flow | mgd |
| Mt. View flow | mgd |
| pH for total plant flow | pH units |
| DO #1 | mg/liter |
| DO #2 | mg/liter |
| DO #3 | mg/liter |
| DO #4 | mg/liter |
| Airflow #1 | cfm |
| Airflow #2 | cfm |
| Airflow #3 | cfm |
| Airflow #4 | cfm |
| Thickener #1 flow | gpm |
| Thickener #1 density | Percent of full scale |
| Thickener #2 flow | gpm |
| Thickener #2 density | Percent of full scale |
| Thickener #3 flow | gpm |
| Thickener #3 density | Percent of full scale |
| Thickener #4 flow | gpm |
| Thickener #4 density | Percent of full scale |
| RAS flow | mgd |
| WAS flow | mgd |
| MLSS | mg/liter |
| Chlorine flow #1 | lb/day |
| Chlorine flow #2 | lb/day |
| Chlorine flow #3 | lb/day |
| Chlorine residual #1 | mg/liter |
| Chlorine residual #2 | mg/liter |
| Chlorine residual #3 | mg/liter |
| Sulfer dioxide flow | lb/day |
| Filtered DO (1) | mg/liter |
| Filtered DO (2) | mg/liter |
| Filtered MLSS (1) | mg/liter |
| Filtered MLSS (2) | mg/liter |

## Table 3. LABORATORY DATA

RAW SEWAGE SS
RAW SEWAGE BOD
RAW SEWAGE TOC
RAW SEWAGE COD
FINAL EFF SS
FINAL EFF BOD
FINAL EFF TOC
FINAL EFF COD
RAW SEWAGE NH3
RAW SEWAGE NO2
RAW SEWAGE NO3
RAW SEWAGE ORTHO PHOS
PRIMARY EFF SS
PRIMARY EFF BOD
PRIMARY EFF TOC
PRIMARY EFF COD
PRIMARY EFF NH3
PRIMARY EFF NO2
PRIMARY EFF NO3
PRIMARY EFF ORTHO PHO
SECONDARY EFFLUENT SS
SECONDARY EFF BOD

RAW SEWAGE PH
PRIMARY EFF PH
SECONDARY EFF PH
FINAL EFF PH
MIXED LIQUOR TEMP
MIXED LIQUOR SVI
MIXED LIQUOR SS
MIXED LIQUOR VSS
MIXED LIQUOR DO
MIXED LIQUOR SET VOL
RETURN SLUDGE SS
WASTE SLUDGE SS
SECONDARY EFF TOC
SECONDARY EFF COD
SECONDARY EFF NH3
SECONDARY EFF NO2
SECONDARY EFF NO3
SECONDARY EFF ORPHOS
FINAL EFF NH3
FINAL EFF NO2
FINAL EFF NO3
FINAL EFF ORTHO PHOS

computed variables will consist of:

   a. Typical Process Data - mean, minimum, maximum and standard deviation of the process variables.

   b. Daily composite lab data

   c. Daily loading of important performance variables

   d. Daily efficiency of contaminant removal for each of the four stages of the plant

   e. Daily average respiration loading (lbs. loading/1000 ft.$^3$ of aeration tankage)

2. Monthly data for the 28-day period of each phase. This was later utilized to compare the long-term performance of each control strategy. Specific variables to be computed included;

   a. Process data for the period - mean, minimum, maximum and standard deviation of each variable. This was later used to compute, for example, the average DO level attained for the month.

   b. Loading data summary

   c. Plant air consumption (allows cost comparison associated with DO control)

   d. Monthly efficiency (for comparison of contaminant reduction levels)

   e. Respiration summary.

# SECTION VII

# HARDWARE AND SOFTWARE IMPLEMENTATION

The implementation of the instrumentation and computer systems were paramount to the successful completion of this project. This included hardware installation, calibration and checkout, and software integration. This section discusses these aspects of the instrumentation and computer system. Table 4 summarizes costs and maintenance data on the instrumentation, while Table 5 and 6 summarize similar information on the computer system.

## INSTRUMENTATION

The DO system at Palo Alto consists of four Weston & Stack "Model A40" probes and four "Model 3000-1A" DO analyzers. These probes were originally installed as part of the original plant construction.

All the DO probes were cleaned, checked and calibrated initially (DO-Probe membranes must be periodically cleaned since they tend to clog, resulting in lower readings and poor sensitivity). Cleaning operations were performed once every two weeks, usually taking about one hour to clean and check all probes. Approximately once every three months, all probes were checked, cleaned, and recalibrated. This normally required about four hours for all probes.

The output of the DO analyzers is a 4-20ma. signal. This signal proved to be very noisy (electrically), probably resulting from the small oscillatory variations of the rotor of the DO probe. A first order filter was employed in the computer to "smooth" out the signal. Additional filtering was provided by a polynomial filter in the DO controller.

The DO controller, as implemented, used only one DO probe. The original cost of a single DO system as above was about $1500. Since these were originally installed as part of plant construction, there was no additional cost to this project. (See Table 4).

### Suspended Solids Meter

The MLSS suspended solids meter originally purchased for this project was the Keene "Model 8200 SCCS". Installation of the probe was straightforward using simple pipe mounts. Shortly after installation, the instrument failed. The problem was traced to a leak in the probe seal. The probe was then disassembled, dried out and then reassembled.

The probe was reinstalled but failed to lend itself to a stable calibration. A Keene factory engineer checked the Keene meter. The probe assembly was replaced, the instrument was recalibrated, and it since has been working quite well (Figure 14).

Table 4. INSTRUMENT COSTS

| | | | | Monthly | | | |
|---|---|---|---|---|---|---|---|
| Instrument | Cost<br>$ | Installation[a] | | Utilities[b]<br>$ | Supplies<br>$ | Maintenance[a] | |
| | | $ | MH | | | $ | MH |
| DO Probe | 1,500 | 600 | 40 | nil | 5 | 45 | 3 |
| MLSS Meter | | | | | | | |
| Keene | 3,500 | 240 | 16 | nil | 0 | 15 | 1 |
| Biospherics | 2,400 | 120 | 8 | nil | 0 | 15 | 1 |
| Respirometer | 5,200 | 600 | 40 | 33[c] | 5 | 15 | 1 |
| TOC Analyzer | 10,450 | 600 | 40 | 16 | 5 | 480 | 32 |

[a] Assuming $15/man-hour ($15/MH)

[b] Assuming water at 20¢ per 1,000 gallons and electricity at 1¢ per KWH

[c] Respirometer uses up to 200 gallons of water per hour.

A Biospherics "Model 52L" suspended solids meter was next installed, and the data correlated quite well with the laboratory results (Figure 14). It was used for the MLSS test. It did fail once, necessitating a replacement capacitor in the control unit.

Both instruments track diurnal variations quite well. During the Air/RAS testing, the Keene instrument was biased higher than the Biospherics. After a bias adjustment, the Biospherics read higher, but this has since been more carefully "zeroed out".

Both instruments have been otherwise maintenance-free. The Keene has the advantage of a direct digital readout in PPM, and no moving parts. The Biospherics unit is self-cleaning (not a problem here); hence, it has some moving parts. Eventually this will require replacement of an "O" ring. While the Biospherics unit has a meter readout, it has two scales (0-3000 PPM and 0-10,000 PPM), and the Keene unit covered a range of 500-5000 PPM digitally. The Biospherics thus can also be used to measure return activated sludge concentrations if desired.

The original Keene suspended solids meter was purchased for $3,500. The total installation time was about two man-days (including running of cable). The Biospherics unit has a purchase price of $2,400. Its installation took about one man-day (see Table 4). Both meters were installed in aerator number one, adjacent to each other.

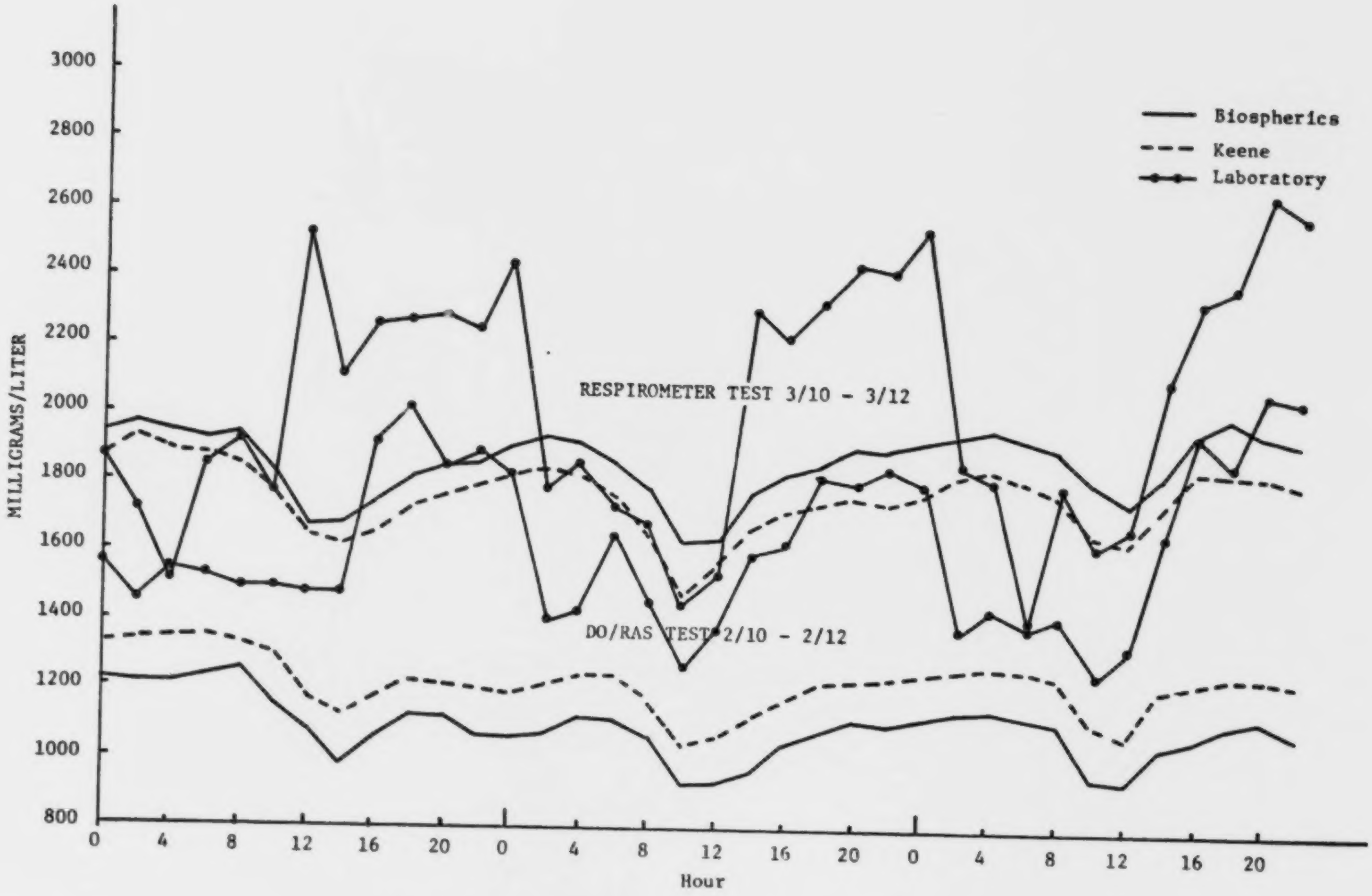


FIGURE 14. SUSPENDED SOLIDS METER COMPARISONS

### Respirometer

The respirometer that was used was a Badger "Model OD 2000". Initial installation of the instrument took about five man-days, due to some necessary plumbing work (shown schematically in Figure 15). The instrument needed sample, water, and drain connections.

Initially, the instrument was plagued with an electronic problem that resulted in erratic output signals. Once this was corrected, the instrument proved very successful. One additional problem that was encountered was a failure of the sample pump. This was repaired by plant personnel within one hour; since then, the instrument has been very reliable. Figure 16 shows the signal output from the respirometer.

The original purchase price of the respirometer was $5,200. In addition, a supply of soda lime is needed to absorb carbon dioxide in the system. The soda lime requires replacement once every two weeks based on a respiration cycle of one four-liter sample every hour (Table 4).

### TOC Analyzer

The TOC analyzer provided for this project was an Astro-Ecology "Model 1000". The installation of this instrument took about one week and required connections for sample, water, plant air and a drain. (see Figure 17).

The TOC analyzer initially suffered from considerable calibration drift (20-30%/week) requiring frequent recalibration. Several times within a three-week period, the reaction-chamber output-line plugged. At the end of this time, the infrared (IR) analyzer gave unstable readings.

The IR analyzer was cleaned and checked out, then (with the cooperation of Astro Ecology representatives, Palo Alto instrument engineers, and the U.S. Environmental Protection Agency) the analyzer was modified. The drain connection was relocated and a new filter was installed prior to the IR inlet.

Performance of the analyzer improved with approximately 10-20% drift/week. To maintain this degree of stability, daily cleaning (water rinse) was necessary.

Unfortunately, because of cumulative delays in making the TOC analyzer operational, it became necessary to delete the TOC feedforward, control-loop evaluation.

The purchase price of the TOC analyzer was $10,450. See Table 4 for a summary of these costs.

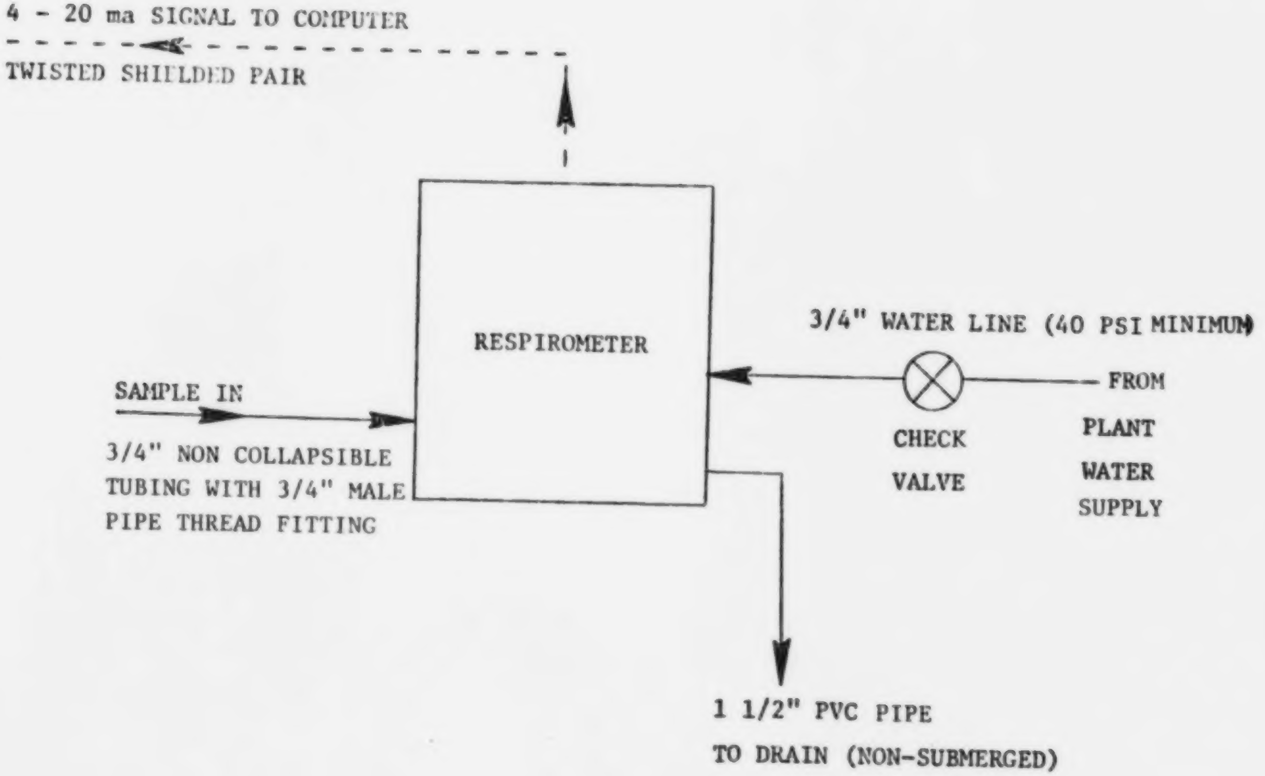

4 - 20 ma SIGNAL TO COMPUTER
TWISTED SHIELDED PAIR
RESPIROMETER
SAMPLE IN
3/4" NON COLLAPSIBLE
TUBING WITH 3/4" MALE
PIPE THREAD FITTING
3/4" WATER LINE (40 PSI MINIMUM)
FROM
PLANT
WATER
SUPPLY
CHECK
VALVE
1 1/2" PVC PIPE
TO DRAIN (NON-SUBMERGED)

FIGURE 15. RESPIROMETER SCHEMATIC DIAGRAM

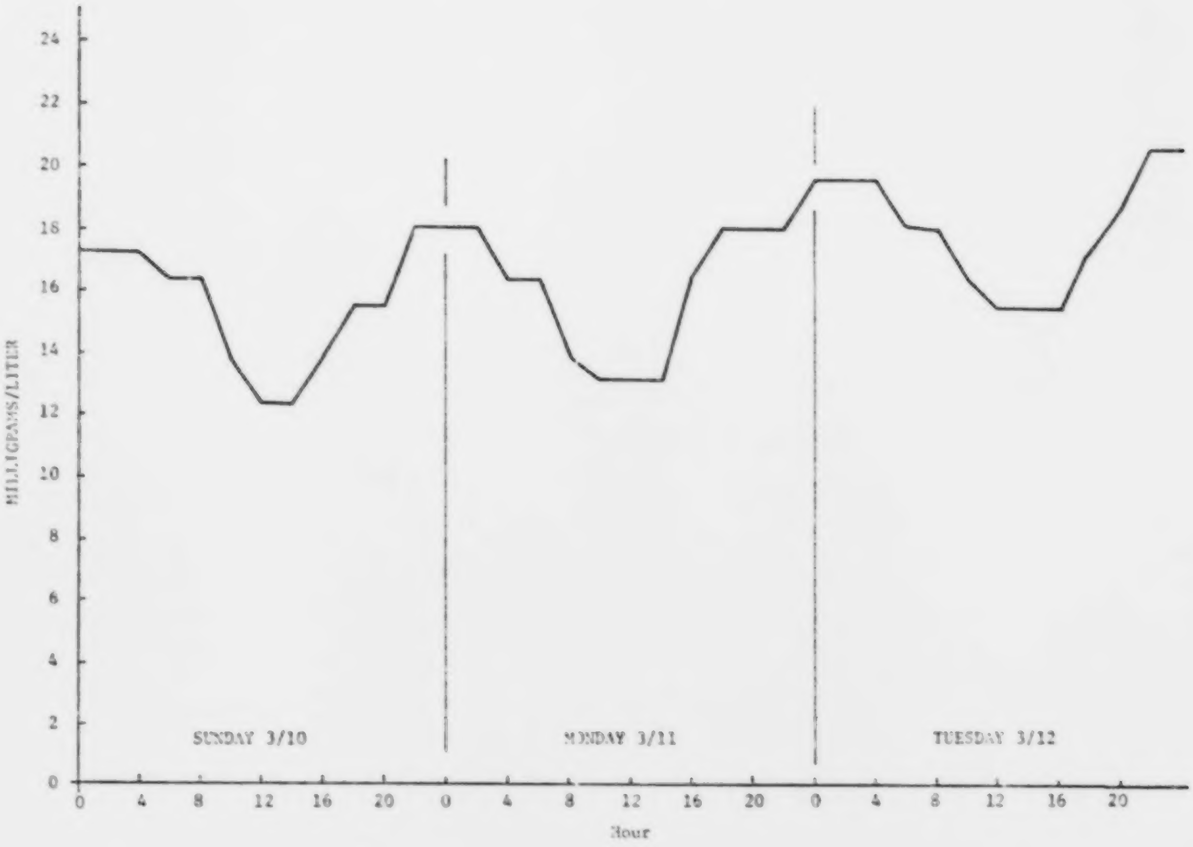


FIGURE 16. BADGER RESPIROMETER PERFORMANCE IN mg/LITER/45 MINUTES

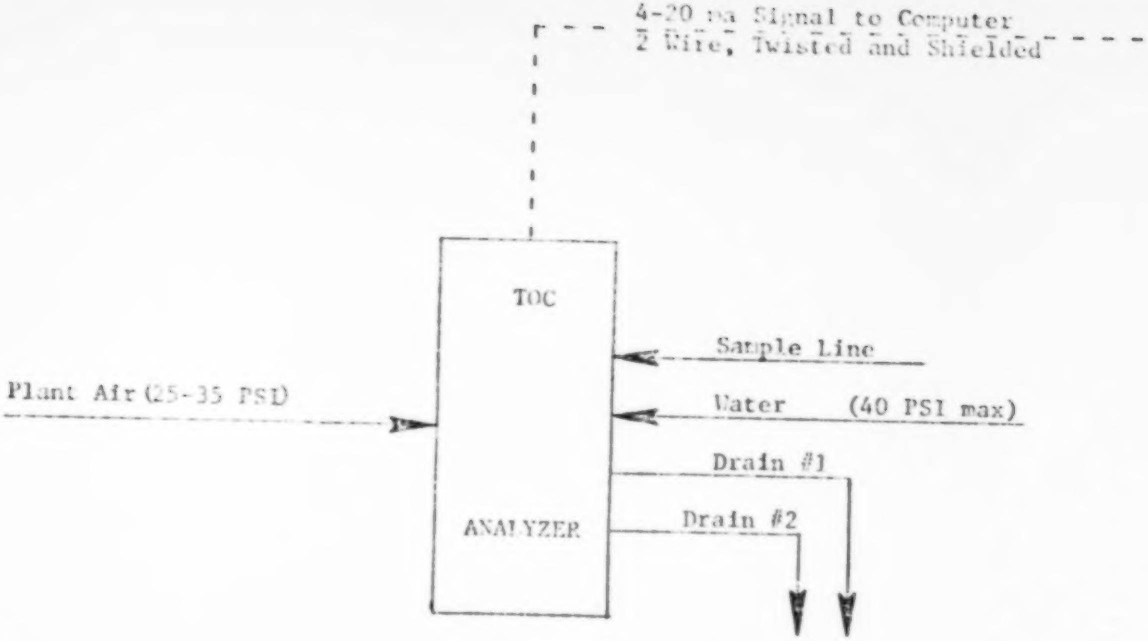

4-20 ma Signal to Computer
2 Wire, Twisted and Shielded
TOC
ANALYZER
Plant Air (25-35 PSI)
Sample Line
Water (40 PSI max)
Drain #1
Drain #2

FIGURE 17. SCHEMATIC DIAGRAM TOC ANALYZER INSTALLATION

## COMPUTER SYSTEM

The computer system at Palo Alto was an IBM System/7, with 16K words of main storage and 2.5 million words of moving head disk storage. Additional equipment included a teletype for input and output, a magnetic tape drive, and a keypunch/card reader. The process I/O included 32 analog inputs, 80 digital inputs, and 32 digital outputs. (See Figure 18).

The installation of the computer hardware was performed by IBM personnel. The City of Palo Alto had to provide the appropriate electrical power (220 volts AC at 4.6 KVA) and the proper type of IBM connector. In addition, a solid ground connection was required, which was also used by the plant instrumentation. Upon completion of these tasks, the computer system was operative.

To complete the computer installation, both process measurements (analog), and equipment/alarm status (digital) had to be wired into the computer. This was done by parallel connection from panel instrumentation (existing) to screw terminals in the computer. The total effort of City personnel to perform these tasks was one man-month.

The system software was based around the Application Module Library (AML/7), which is a standard IBM product. This software routinely takes care of scanning, alarming, engineering units conversion, and scheduling of control and data-management programs on any one of eight clock frequencies. In this case, 6 seconds, 30 seconds, 1 minute, 2 minutes, 30 minutes, 1 hour, 8 hours, and 24 hours. The basic scanning and alarming takes place on a six-second cycle.

One additional key program that was provided by IBM, on a custom basis, was the PAX monitor. This program takes care of multiple partition core allocations and queuing of programs from disk for these core partitions, both from program-program requests and from keyboard requests. Thus, the Palo Alto system has a type of foreground/background processing capability allowing data management and other types of programs to be executed concurrently with scan-and-control functions. The development of this program and an on-line card read program allowed essentially continuous computer operation.

With the availability of the PAX program, it was possible to begin testing control strategies on-line. All of the control programs were written in assembly language (MSP/7 and AML/7). All program assembly/compilation for this project was performed via a telecommunications link to an IBM 370 in San Francisco.

Process data were routinely written into disk storage every two minutes. The disk unit allowed storage of up to eight days worth of data. Once a week, this data was transferred to magnetic tape for later off-line

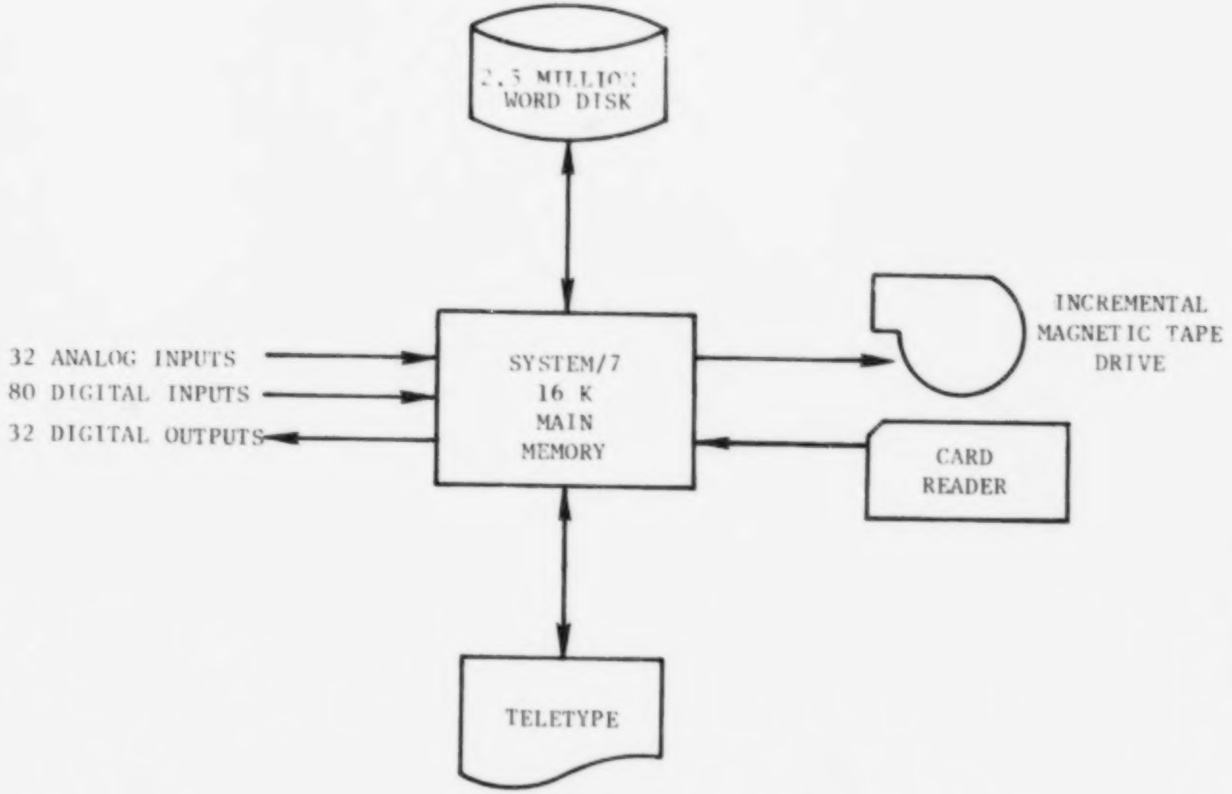

2.5 MILLION WORD DISK
32 ANALOG INPUTS
80 DIGITAL INPUTS
32 DIGITAL OUTPUTS
SYSTEM/7
16 K
MAIN
MEMORY
INCREMENTAL
MAGNETIC TAPE
DRIVE
CARD
READER
TELETYPE

FIGURE 18. COMPUTER CONFIGURATION

analysis. This disk data base was fundamental to the various data management reports. These included:

- Hourly Log
- Shift Report
- Daily Report
- Laboratory Data Entry.

Off-line analysis of the process and laboratory-taped data was performed on an IBM/370, with all analysis programs written in FORTRAN IV. A summary and brief description of all programs provided is shown in Table 5.

Computer system failures usually were of two types: fatal and non-fatal. A fatal failure would either completely stop the system or prevent writing of data to disk; problems of this type included disk failure, memory failure, or teletype failure. Non-fatal problems only required downtime to correct the problem; they did not interfere with normal data collection and control. Examples of this type of failure were analog input, digital input, process interrupt, and magnetic tape failures. Table 6 shows a summary of the computer system failures that occurred during this study.

The most pronounced failure that was observed was that of the disk system. Periodically, it would "stall" and fail to record process data. This condition was not obvious to plant personnel and often would go undetected for several hours. The problem was apparently due to some marginal voltages within the computer, and has been rectified.

Another problem that still has eluded repair was that of the magnetic tape system. It occasionally writes data incorrectly, and this malfunction is usually not discovered until the tape is processed by the off-line analysis programs. This usually resulted in a loss of either process or laboratory data. Not all of these incidents have been recorded.

The purchasing costs of computer hardware of the size and capability described above would range from $60,000 to $140,000. To that, add contract maintenance which would be in the range of $100-$500 per month. A possible alternative to contract maintenance is on-call maintenance which would be between $15-30 per hour, plus expenses and parts. If leasing arrangements are available, they would run between $1400-$4000 per month and would normally include all maintenance and spare parts. Table 7 shows a summary of computer costs.

## Table 5. PALO ALTO COMPUTER PROGRAMS

AUTOMATIC PROGRAMS

1. SCAN - performs all scanning and conversion to engineering units on a 6-second cycle. This program resides in core at all times and uses data from the SCAN table (i.e., table driven).
2. LIMIT CHECK & ALARM - performs limit checking and alarming on high or low limit conditions. This program also uses data in the SCAN table.
3. DISK WRITE - writes all process data to disk every two minutes. This data is later retrieved by the magnetic tape program or the report programs.
4. LOG - prints a log of all process variables that are enabled on the teletype every one hour. This frequency is changeable, but for convenience has been set to one hour.
5. SCAN UPDATE - enables all analog points at midnight every night. This is to insure continuation of scanning for points that may have been disabled during the day.
6. 8/24 HOUR REPORT - prints a summary report of process variables every 8/24 hours. This is the same program as REPORT, but with default values.
7. MONITOR - performs scheduling of programs from disk, in response to either keyboard requests or program requests.
8. DO CONTROL (C001) - the DO controller runs on a one minute cycle and as implemented uses proportional plus integral action. A four-point polynomial filter is included which also calculates the first derivative.
9. MLSS CONTROL - (C004) - the MLSS control is essentially the same as the DO control except it runs on a 30-minute cycle, and presently uses only proportional action.
10. DO/RAS CONTROL (C005) - this program runs on a 30-minute cycle and calculates the necessary change in the return activated sludge rate.
11. RESPIROMETER CONTROL (C005) - this program runs on a 30-minute cycle, and using the respirometer reading, calculates the necessary change in the RAS rate.

ON DEMAND PROGRAMS

1. KEYBOARD UTILITY - is a collection of short programs to get/put data into the SCAN tables, enable points, change setpoints, and dump/patch core.
2. CARD READ - reads object cards (programs produced by the host computer) into pre-assigned areas on desk. Once the program is on disk, it can be catalogued using the DIRECTOR program.
3. DIRECTOR - establishes a name/number correspondence between programs and disk area. Once the program is catalogued, it can be executed either by keyboard request or program request.
4. MAGNETIC TAPE WRITE - writes process and laboratory to magnetic tape. In both cases an entire day's worth of data is written each time a write request is given.
5. DISKLIST - writes data from disk to the teletype. The operator specifies the time and points of interest, and then an hour's worth of data is written.
6. LAB - reads and writes data from the teletype to the disk laboratory files. Lab data is entered for a particular day and hour (hour 23 being composite data).
7. AIR - prints out on the teletype the value of each air blowing rate and each DO meter in the secondary aerators.
8. SOLIDS - is an offline program that uses keyboard entered data to calculate centrifuge performance. This program is used primarily for polymer evaluations.
9. CALCULATOR - is an algebraic type of calculation program. Expressions are equated; then, any combination of add, subtract, multiply, and divide calculation can be performed on these variable and printed out.

## Table 6. COMPUTER SYSTEM FAILURES

| Date | Description | Fatal | Repair Time (hours) | Data Loss (hours) |
|---|---|---|---|---|
| 11/13/72 | Memory Parity | No | 1.5 | |
| 10/27/72 | TTY Motor Relay | Yes | 1.6 | 5 |
| 12/ 5/72 | Analog Input | No | 1.25 | |
| 2/21/73 | Digital Input | No | 3.5 | |
| 3/ 9/73 | Disk | Yes | 2 | 4 |
| 3/19/73 | Disk | Yes | 3 | 2 |
| 3/21/73 | Magnetic Tape | No | 1.75 | |
| 5/26/73 | Disk | Yes | 1.0 | 3 |
| 6/ 6/73 | Disk | Yes | 1.5 | 6 |
| 6/ 8/73 | Process Interrupt | No | 1.3 | |
| 7/20/73 | Digital Input | No | 2.0 | |
| 8/ 5/73 | Disk | Yes | 0.5 | 13 |
| 8/13/73 | Magnetic Tape | No | 1.75 | |
| 8/16/73 | Magnetic Tape | No | 1.40 | |
| 8/28/73 | Memory Parity | Yes | 4.0 | 3 |
| 8/29/73 | TTY Motor | Yes | 1.5 | 4 |
| 10/24/73 | Disk | Yes | 0.5 | 3 |
| 10/24/73 | Analog Input | No | 1.75 | |
| 1/11/74 | Disk | Yes | 0.5 | 4 |
| 1/21/74 | Disk | Yes | 0.5 | 2 |

## TABLE 7

## TYPICAL COMPUTER COSTS*

| | | |
|---|---|---|
| **PURCHASE** | | |
| Computer Cost | $60,000-$140,000 | (one time) |
| Maintenance | $100-$500/mo. | $1200-$6000/yr. |
| **LEASE** | | |
| Computer | $1400-$4000/mo. | $17,000-$48,000/yr. |
| **OTHER** | | |
| Utilities (3-6KVA)<br>@ 1¢/KWH | $22-$44/mo. | $260-$520/yr. |
| Supplies (paper,cards) | $15-$25/mo. | $180-$300/yr. |

*These costs are for a system of the configuration shown in Figure 4.6. This DOES NOT necessarily represent the ideal or lowest cost configuration necessary to accomplish these functions.

## SECTION VIII

## PERFORMANCE OF AUTOMATED STRATEGIES

In analyzing the data from the various control-alogrithm tests, two evaluation criteria must be considered. The first criteria is an assessment of whether or not the controller functioned as it was intended. The algorithms developed here are all basically regulators for maintaining constant levels of DO, MLSS, or F/M. Thus, time-history examination of the controlled variable in comparison to a manual test, reveals the quality of regulation.

Second, and most important, the impact of the controller on plant operation must be determined. The two major areas of demonstrable benefits are:

- Effluent Quality Improvement
- Operating Cost Savings.

Comparisons are made between plant-performance indices developed from data gathered both manually and automatically in order to quantitatively measure benefits derived from automatic control.

Comparative data for the controller evaluations was developed in two manual-test periods. The first, Manual Test I, was performed in the dry season (April thru October) when the plant was operating in the contact stabilization mode. This period is used as a reference for the DO and MLSS controllers which were also tested in the dry season and with the plant operated in the contact stabilization configuration. Manual Test II, in the wet season (November thru March) and with the plant in the conventional secondary treatment configuration, is used to compare operation with the Air/RAS and Respirometer/RAS controllers. Summaries of all the test-period averages for important operational parameters are given in Table 8.

### DO CONTROLLER

The intent of the DO controller was to adjust the air flow to the aerators in the secondary treatment process in response to changes in biological respiration demands. The mechanism of control was to maintain the DO concentration in the secondary aerators at a constant value.

Figure 19 shows the time-history results of the DO controller for the three-day intensive test period. DO was maintained very close to the 1.0-mg/l setpoint most of the time despite very large changes in the air requirements. Comparison of Figure 19 with Figure 20 (data for manual test I) shows the wide excursions in DO that resulted from the standard (i.e., manual) procedure of twice daily scheduled, air-blowing-rate

Table 8. AVERAGES FOR OPERATING VARIABLES FOR A 30-DAY TEST PERIOD

| Test | Plant Flow, mgd | Plant Loading, lb $BOD_5$/day | Return Activated Sludge, mgd | Mean Cell Residence Time, Days | Average Dissolved Oxygen, mg/L | Test Period, Days | Season | Operating Configuration |
|---|---|---|---|---|---|---|---|---|
| MANUAL I<br>7/9/73 to<br>8/7/74 | 24.0 | 31,750 | 8.9 | 10 | 1.29 | 30 | Dry | Contact Stabilization |
| DO<br>9/16/73 to<br>9/11/73 | 23.6 | 38,100 | 8.7 | 10 | 1.04 | 31 | Dry | Contact Stabilization |
| MLSS<br>9/16/73 to<br>10/16/73 | 26.0 | 33,700 | 11.0 | 10 | 1.26 | 31 | Dry | Contact Stabilization |
| MANUAL II<br>10/28/73 to<br>11/27/73 | 29.0 | 42,300 | 12.6 | 10 | 1.02 | 31 | Wet | Conventional |
| AIR/RAS<br>1/13/74 to<br>2/12/74 | 26.7 | 39,500 | 11.5 | 10 | 0.78 | 31 | Wet | Conventional |
| RESPIROMETER/RAS<br>2/13/74 to<br>3/12/74 | 24.7 | 31,700 | 12.8 | 9 | 0.86 | 28 | Wet | Conventional |

changes. The superiority of automatic control for regulating to a DO desired setpoint is thus demonstrated.

It should be pointed out that in the process of following the computer's DO-controller commands, the operators became adept at anticipating the air-flow requirements themselves by observing the DO strip chart on the control panel. Figure 21 shows the Manual Test II intensive results, and indicate a considerable reduction in DO deviation over Manual Test I. The operators in effect employed analog man in the loop DO control during Manual Test II. The operator can therefore perform the control task himself with proper training and experience; however, the frequent adjustments in control settings (on the order of once every two minutes during periods of rapid variations in respiration) are very wasteful of an operator's time, as well as being very monotonous. Automatic control, when compared to nearly continuous manual monitoring, is far less costly and produces better results since the machine will not lose interest in a dull task.

## Benefits

The prime benefit expected of the DO controller was power cost savings due to reduced average-air-supply requirements. Air use is minimized by maintaining the DO at the lowest level consistent with good effluent quality. The operating point of 1.0 mg/l DO for the test period was selected after consultation with Palo Alto operating personnel. No exploration to determine the absolute minimum DO level was undertaken.

Table 9 shows the removal efficiencies, broken down by unit process, for both the DO and Manual I tests. Of primary interest are the secondary process results since that is where the major impact of the DO controller should be. Direct comparison of the mean of the secondary process removal efficiency must be tempered by statistical considerations, however, the standard error of the mean estimates, $\sigma_m$, given in Table 9 is:

$$\sigma_m = \frac{\sigma}{\sqrt{n}} \qquad (21)$$

where n is the number of days for which the mean efficiency is calculated and $\sigma$ the standard deviation of its removal efficiencies.

At the 95% confidence level, for the differences between mean removal efficiencies, only the secondary TOC removal efficiencies show statistically significant differences, of approximately 13% better than for the manual period when compared to automatic DO control. Since the other removal efficienceis -- $BOD_5$, COD and SS -- are all higher for the DO controller, however, one might conclude that there is a definite improvement in net efficiency for secondary treatment with the DO controller.

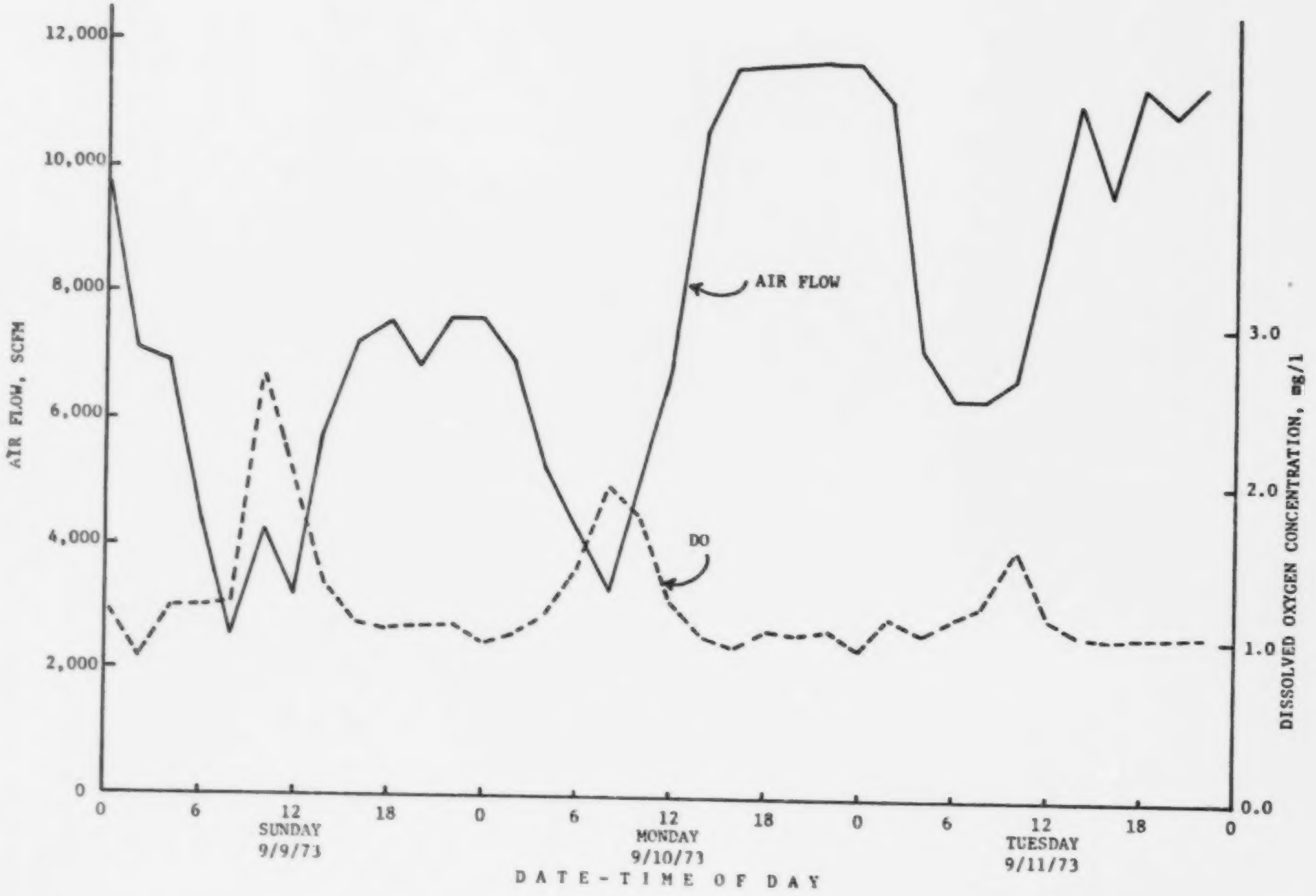


FIGURE 19. DO CONTROLLER: DISSOLVED OXYGEN AND AIR FLOW VS. TIME

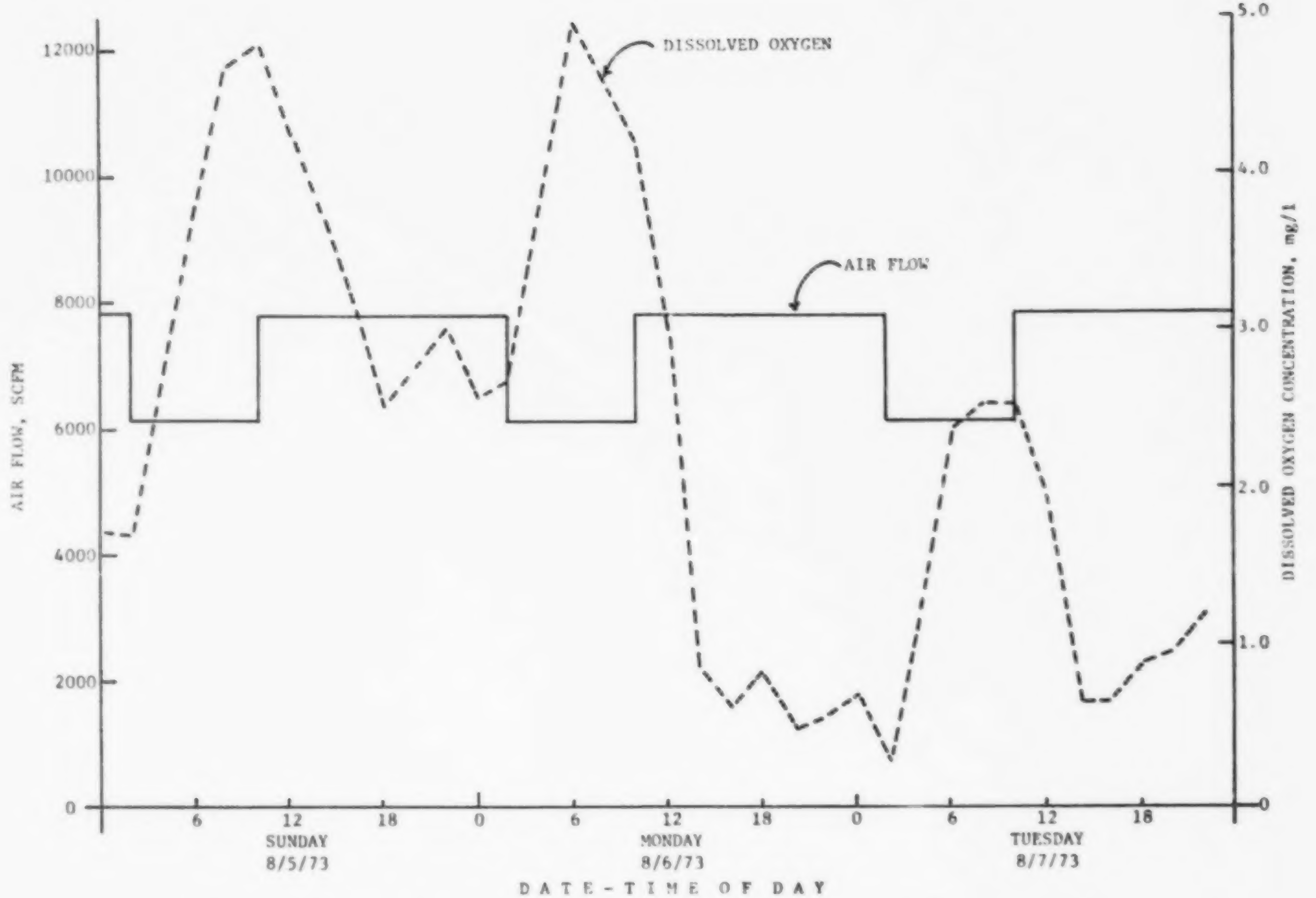


FIGURE 20. MANUAL TEST I. DISSOLVED OXYGEN AND AIR FLOW VS. TIME

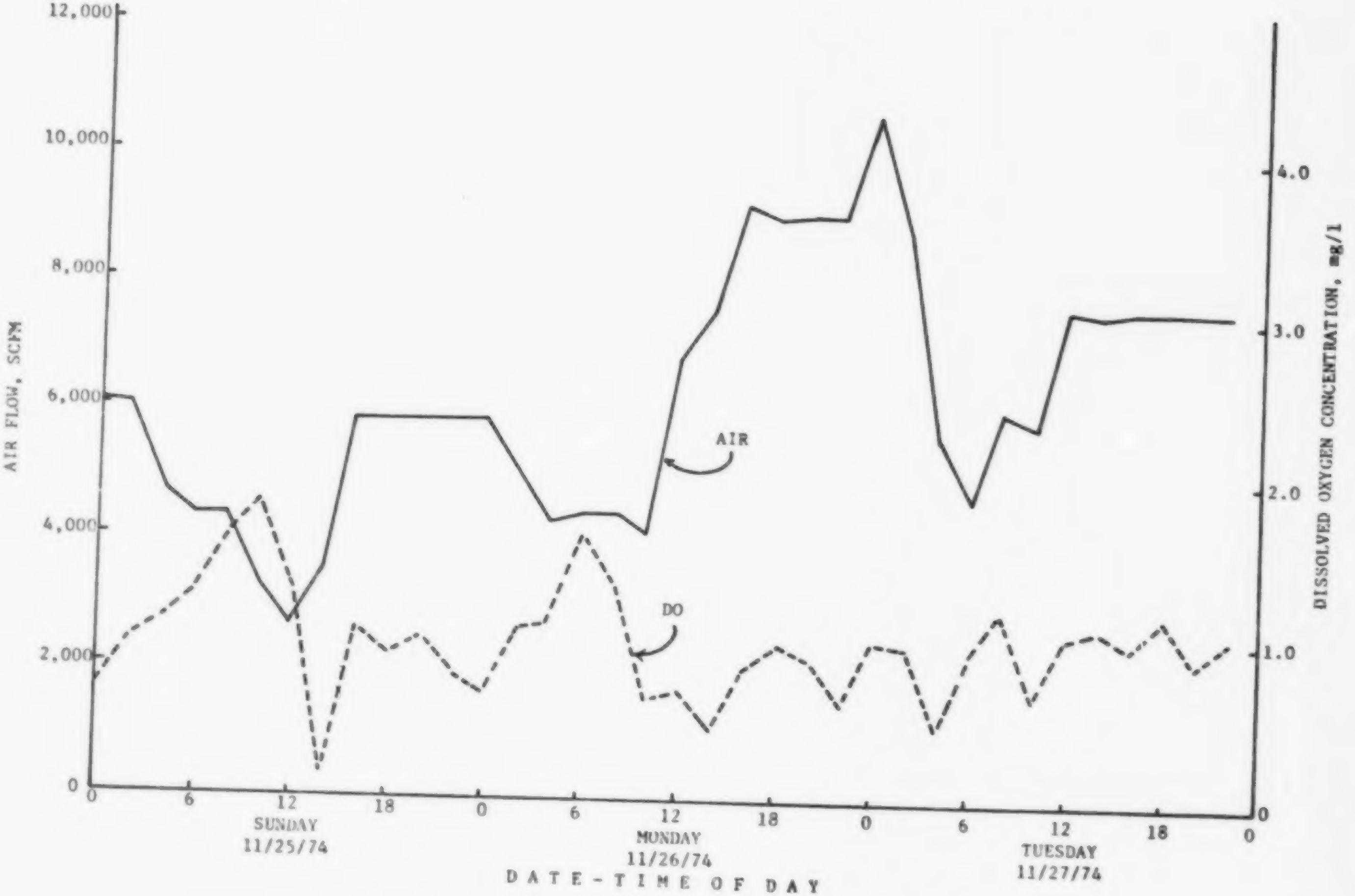


FIGURE 21. MANUAL TEST II: DISSOLVED OXYGEN AND AIR FLOW VS. TIME

If the four measures of waste removal efficiency - SS, $BOD_5$, TOC and COD - are themselves averaged, the net improvement with automatic DO control is 7% relative to Manual Test I.

Figure 22 and 23 are log-normal probability plots of secondary effluent $BOD_5$ and SS concentrations. The DO controller results reveal a very small mean increase in effluent $BOD_5$ over the manual results. There is also slightly more dispersion in the $BOD_5$ for DO control. For suspended solids, the DO controller produced a significant improvement in the mean (30 mg/l, as opposed to 40 mg/l for the manual test) with practically the same dispersion.

Since Table 8 indicates that the conditions of the DO and Manual I tests were very nearly identical except for plant loadings one might conclude that there was a measurable improvement in secondary treatment effluent quality. Given the tighter control of closing the loop and some search for the optimum DO level, it is probable that effluent quality could be further improved.

Table 10 lists the results of the primary areas for significant operating cost savings for all control periods. Only air-compressor power costs are really applicable to the DO controller since the RAS pumping rate was constant and also nearly the same as for the Manual I test. Air use is normalized by secondary treatment $BOD_5$ loading. Reasonable estimates of yearly average $BOD_5$ loading and plant flows are employed to find total material and power consumption. The power costs for air supply are developed below.

No separate direct measure of power use was available on the Palo Alto plant's motor drives for air. A reasonable estimate of the cost of providing air can, however, be determined knowing peak capacities, $Q_{max}$, and motor power ratings, $P_{max}$. Then, with the following assumptions:

- Motor efficiencies, $\eta$, are about 90%
- A linear relationship exists between compressor or pump output and power consumption
- Power costs, $p_e$, at Palo Alto are about 1¢/KWH.

The power cost per unit output, p, can be expressed

$$p = \frac{p_e \, P_{max}}{\eta \, Q_{max}}. \qquad (22)$$

Relevant numerical values for the air power cost per unit output are presented in Table 10.

## Table 9. REMOVAL EFFICIENCIES OVER A 30-DAY PERIOD

A. Modified Contact Stabilization

| Test | Unit | Mean efficiency, % | | | | Days of data | Std deviation of removal efficiency<br>Standard error of mean, % | | | | Equipment in service |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SS | $BOD_5$ | TOC | COD | | SS | $BOD_5$ | TOC | COD | |
| MANUAL I | Primary | 51.4 | 22.9 | 26.1 | 33.6 | 30 | 11.6<br>2.1 | 12.0<br>2.2 | 12.7<br>2.3 | 10.9<br>2.0 | **4 Primary Clarifiers** |
| | Secondary | 46.3 | 83.9 | 53.0 | 63.1 | | 22.4<br>4.1 | 4.5<br>0.8 | 7.6<br>1.4 | 9.0<br>1.6 | **3 Aerators**<br>**3 Secondary Clarifiers** |
| | Plant Total | 77.4 | 87.4 | 66.1 | 75.1 | | 6.3<br>1.2 | 3.2<br>0.6 | 7.0<br>1.3 | 4.9<br>0.9 | **1 Sludge Storage & Reaeration Basin** |
| DO | Primary | 47.7 | 25.8 | 20.0 | 32.5 | 31 | 12.3<br>2.2 | 19.8<br>3.6 | 7.9<br>1.4 | 11.4<br>2.0 | **4 Primary Clarifiers** |
| | Secondary | 52.8 | 84.2 | 59.8 | 63.6 | | 22.3<br>4.0 | 7.5<br>1.3 | 8.4<br>1.5 | 10.3<br>1.8 | **3 Aerators**<br>**3 Secondary Clarifiers** |
| | Plant Total | 78.1 | 84.6 | 66.7 | 74.6 | | 8.0<br>1.4 | 5.8<br>1.0 | 7.3<br>1.3 | 5.2<br>0.9 | **1 Sludge Storage & Reaeration Basin** |
| MLSS | Primary | 47.7 | 25.3 | 22.4 | 35.6 | 31 | 11.0<br>2.0 | 22.4<br>4.0 | 10.7<br>1.9 | 16.1<br>3.0 | **4 Primary Clarifiers** |
| | Secondary | 38.3 | 83.9 | 50.5 | 58.4 | | 26.3<br>4.7 | 7.5<br>1.3 | 13.3<br>2.4 | 13.4<br>2.4 | **3 Aerators**<br>**3 Secondary Clarifiers** |
| | Plant Total | 75.4 | 84.4 | 62.4 | 72.9 | | 6.3<br>1.1 | 9.5<br>1.7 | 8.6<br>1.5 | 6.9<br>1.2 | **1 Sludge Storage & Reaeration Basin** |

Table 9. (continued) REMOVAL EFFICIENCIES OVER A 30-DAY PERIOD

B. Completely Mixed Aeration

| Test | Unit | Efficiency variance, % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean efficiency, % | | | | Days of data | Standard error of mean, % | | | | Equipment in service |
| | | SS | $BOD_5$ | TOC | COD | | SS | $BOD_5$ | TOC | COD | |
| MANUAL II (analog man in the loop DO control) | Primary | 45.4 | 9.1 | 20.4 | 27.6 | 30 | 19.0<br>3.5 | 11.5<br>2.1 | 17.8<br>3.2 | 14.4<br>2.6 | 3 Primary Clarifiers |
| | Secondary | 58.6 | 84.2 | 67.7 | 64.4 | | 27.7<br>5.1 | 11.0<br>2.0 | 12.6<br>2.3 | 13.7<br>2.5 | 4 Aerators |
| | Plant Total | 79.8 | 81.5 | 71.6 | 76.9 | | 13.5<br>2.5 | 11.7<br>2.1 | 9.1<br>1.7 | 6.6<br>1.2 | 4 Secondary Clarifiers |
| AIR/RAS | Primary | 54.5 | 20.0 | 34.8 | 35.4 | 30 | 10.1<br>1.8 | 14.3<br>2.6 | 12.3<br>2.2 | 9.6<br>1.7 | 2 Primary Clarifiers |
| | Secondary | 49.5 | 83.4 | 59.2 | 54.6 | | 25.1<br>4.6 | 5.8<br>1.0 | 12.4<br>2.3 | 13.2<br>2.4 | 4 Aerators<br>4 Secondary Clarifiers |
| | Plant Total | 79.6 | 87.6 | 71.3 | 75.2 | | 9.4<br>1.7 | 6.0<br>1.1 | 7.3<br>1.3 | 7.9<br>1.4 | |
| RESPIROMETER/RAS | Primary | 52.6 | 32.4 | 38.9 | 37.9 | 26 | 20.1<br>3.9 | 16.6<br>3.3 | 16.4<br>3.2 | 16.0<br>3.1 | 3 Primary Clarifiers |
| | Secondary | 63.5 | 84.2 | 63.5 | 65.2 | | 19.7<br>3.9 | 7.7<br>1.5 | 15.8<br>3.1 | 11.0<br>3.3 | 4 Aerators |
| | Plant Total | 83.8 | 91.9 | 75.3 | 79.1 | | 6.2<br>1.2 | 4.2<br>0.8 | 8.5<br>1.7 | 5.8<br>1.1 | 4 Secondary Clarifiers |

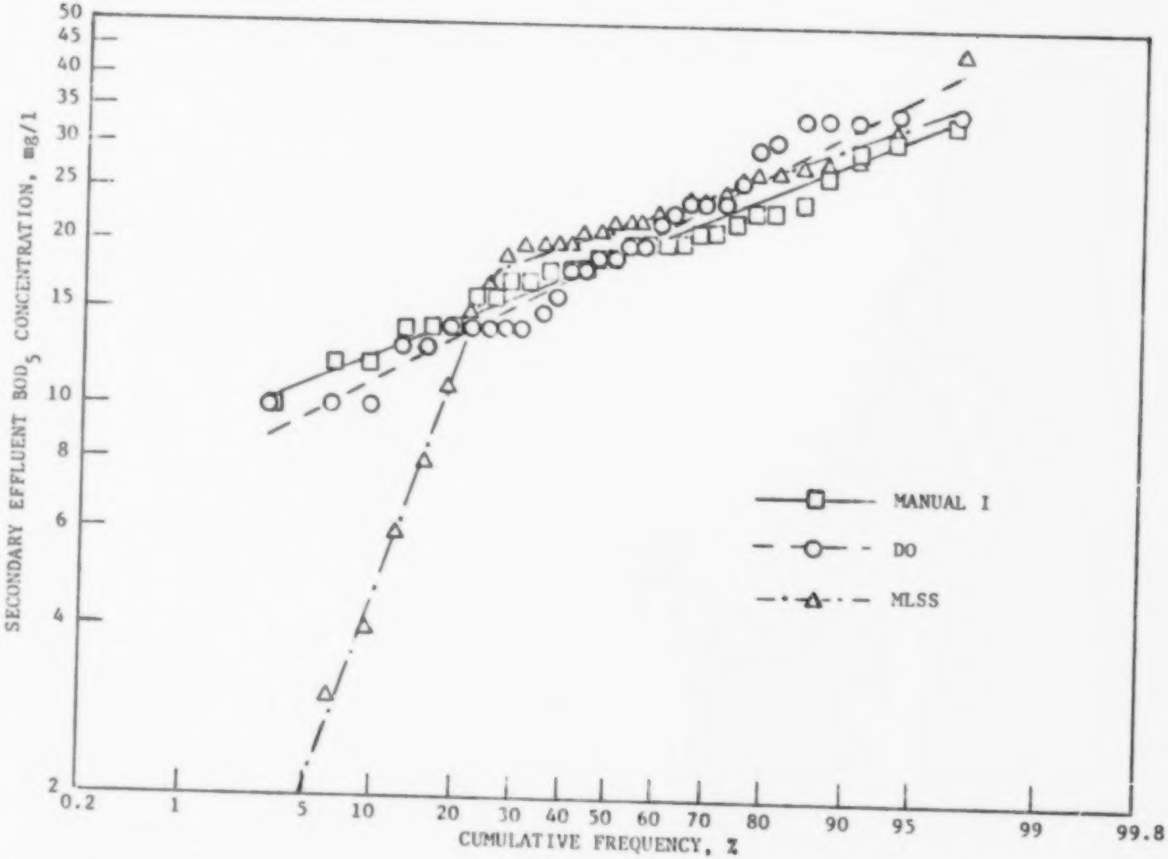


FIGURE 22. DRY SEASON TESTS: SECONDARY EFFLUENT $BOD_5$ CONCENTRATION VS. LOG NORMAL FREQUENCY DISTRIBUTION

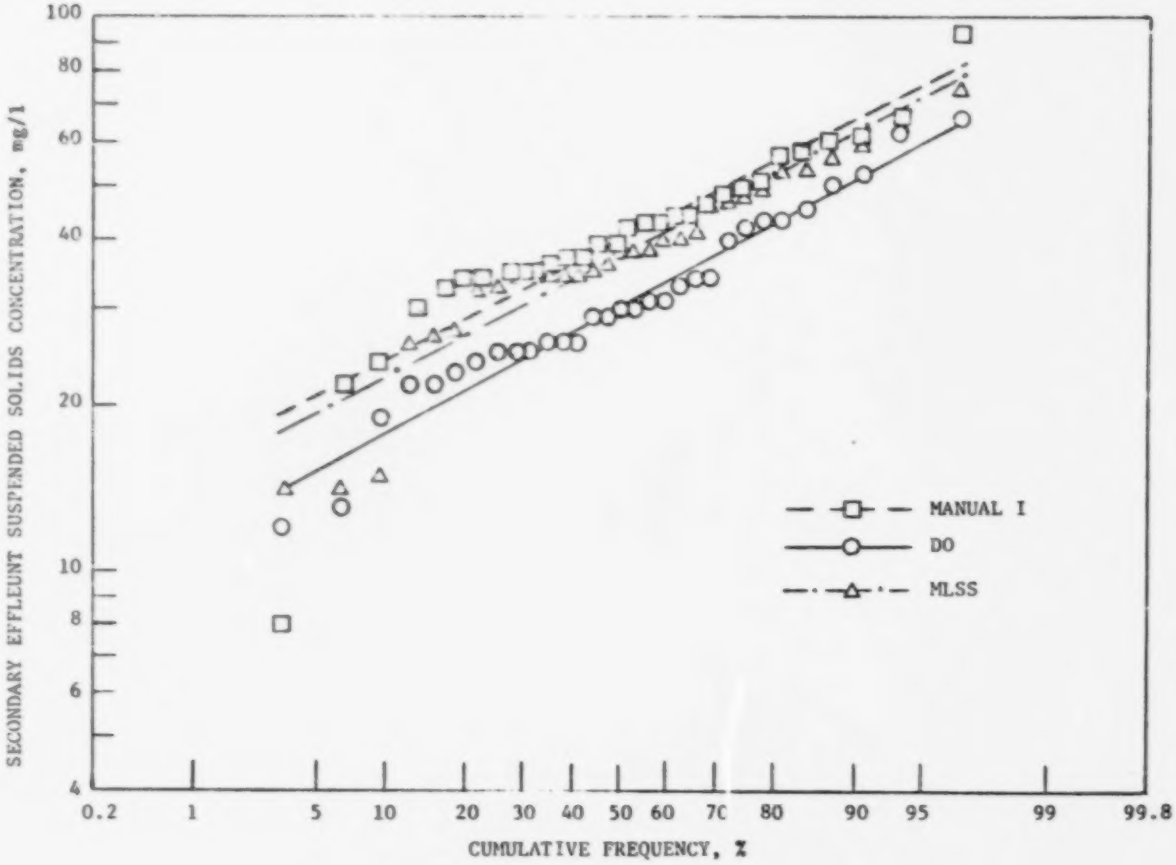


FIGURE 23. DRY SEASON TESTS: SECONDARY EFFLUENT SUSPENDED SOLIDS CONCENTRATION VS. LOG NORMAL FREQUENCY DISTRIBUTION

## Table 10. TEST PERIODS' OPERATING COST COMPARISONS

Yearly Costs Based on These Yearly Averages:
Aerator $BOD_5$ Load = 35,000 lb/day
Plant Flow = 26 MGD

Modified Contact Stabilization

| Test | Air $ft^3$/lb $BOD_5$ in primary effluent | Yearly cost, $ |
|---|---|---|
| Manual I<br>no DO control | 438 | 38,631 |
| Digital (man in the loop) DO control | 377 | 33,251 |
| MLSS no DO control | 507 | 44,717 |
| Completely Mixed Aerator | | |
| Manual II<br>analog man in the loop DO control | 265 | 23,373 |
| AIR/RAS<br>digital man in the loop DO control | 274 | 24,166 |
| RESPIROMETER/RAS<br>digital man in the loop DO control | 419 | 26,956 |

$P_{MAX}$ = 600 hp
$Q_{MAX}$ = 12,000 SCFM
Pe = 0.01 $/KWH
Cost Factor $6.9 \times 10^{-6}$ \$/ft.$^3$

Comparing the DO cost figures with Manual I figures yields dollar cost differential on a yearly basis of $5,380. The reduced air use represents an 11% savings and is a reliable number.

## MLSS CONTROLLER

The MLSS controller attempted to regulate the MLSS concentration in the secondary treatment aerators to a constant value. The MLSS control was a interim algorithm intended for use in cascade control in other algorithms. The MLSS control was tested, therefore, primarily for check out of the MLSS algorithm performance.

Figure 24 is a time-history of MLSS and RAS for the MLSS controller's intensive test period. The Manual I results are illustrated in Figure 25, although the MLSS values shown are suspect due to some difficulties with the solids concentration meter during this period. Manual Test II results in Figure 28 while not directly comparable reveal a more probable diurnal variation in the MLSS without MLSS control. Solids levels in the aerators tank were maintained nearly at setpoint except during periods of low plant flow. One reason for poor control at low plant flow was because the plant's design imposed a low RAS pumping limit of 8.0 MGD (0.03 $Mm^3$/day). The controller setpoint was 1500 mg/l, and it can be seen that the majority of the natural MLSS excursions were in the high direction corresponding to periods where the RAS rate was at its lower limit. For low plant influent flows (night and early morning), the 8.0 MGD (0.03 $Mm^3$/day) RAS rate was too high for the desired solids level so that there was an uncontrolled accumulation of solids in the aerators.

During the MLSS control test, a floating scum and poor settling characteristic developed with the plant operating in the contact stabilization configuration. Table 9 provides a comparison of MLSS-test-removal efficiencies with the Manual I values. All measured quantities -- $BOD_5$, SS, TOC, and COD --secondary treatment efficiencies during operation with MLSS control are somewhat poorer than for the corresponding Manual I results; although, only in the case of SS efficiency do the results differ by an amount that has at least a 95% chance of being statistically significant. Figures 22 and 23 illustrate the secondary effluent $BOD_5$ and SS. The deterioration in the settleability of the sludge forced a change in the plants contact stabilization configuration to the plant's original design (completely mixed configuration) for the rest of the control studies and probably produced the decrease in plant performance.

## AIR/RAS CONTROLLER

The Air/RAS controller was one of the forms of F/M regulation implemented. It was the intent of these controllers to regulate the instantaneous F/M value such that it was at or below a set value. The different forms of F/M control were based on the means of measuring food-uptake-rate. For the Air/RAS controller, food uptake was implied from

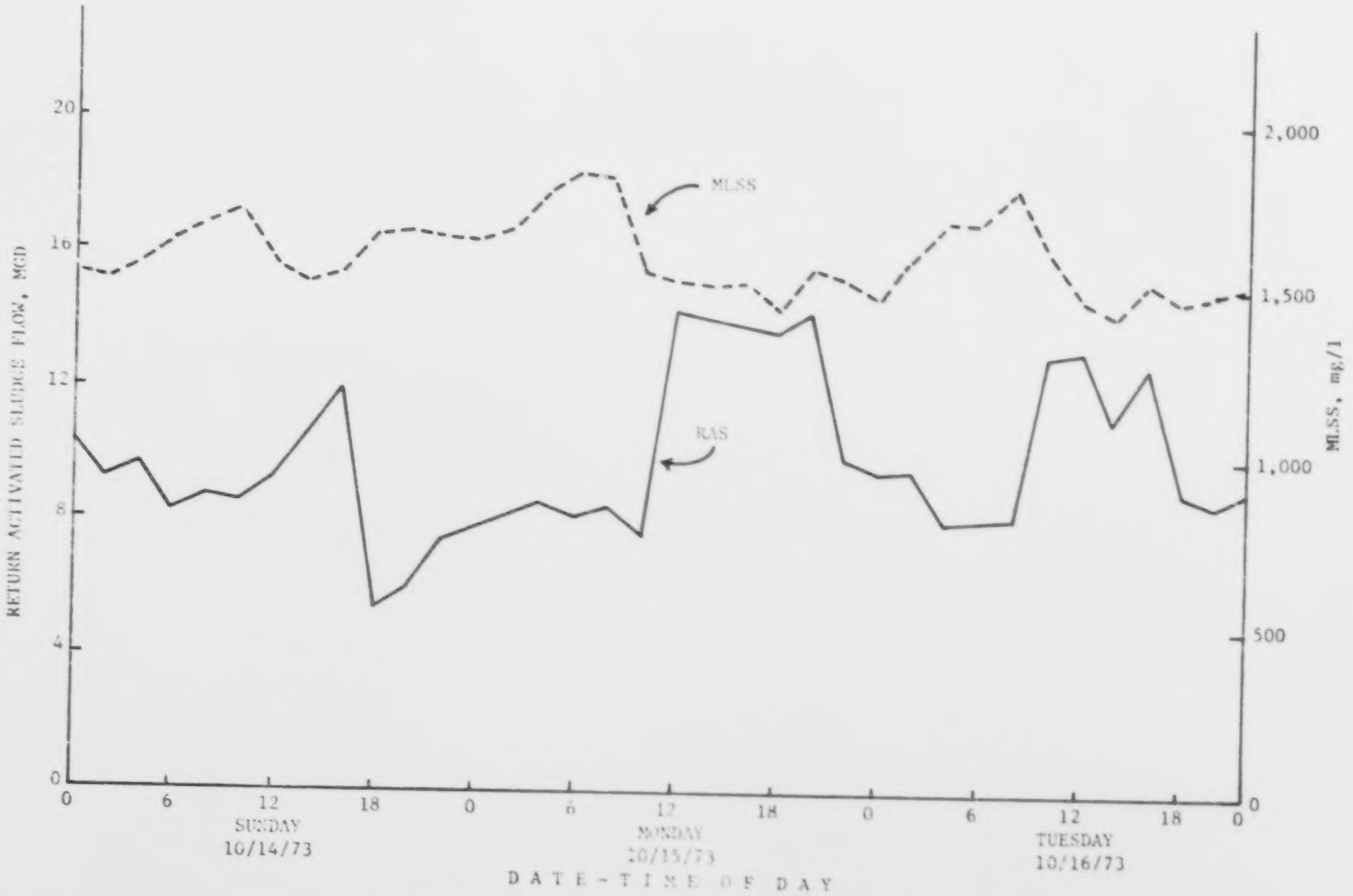


Figure 24. MLSS CONTROLLER: MLSS AND RAS VS. TIME

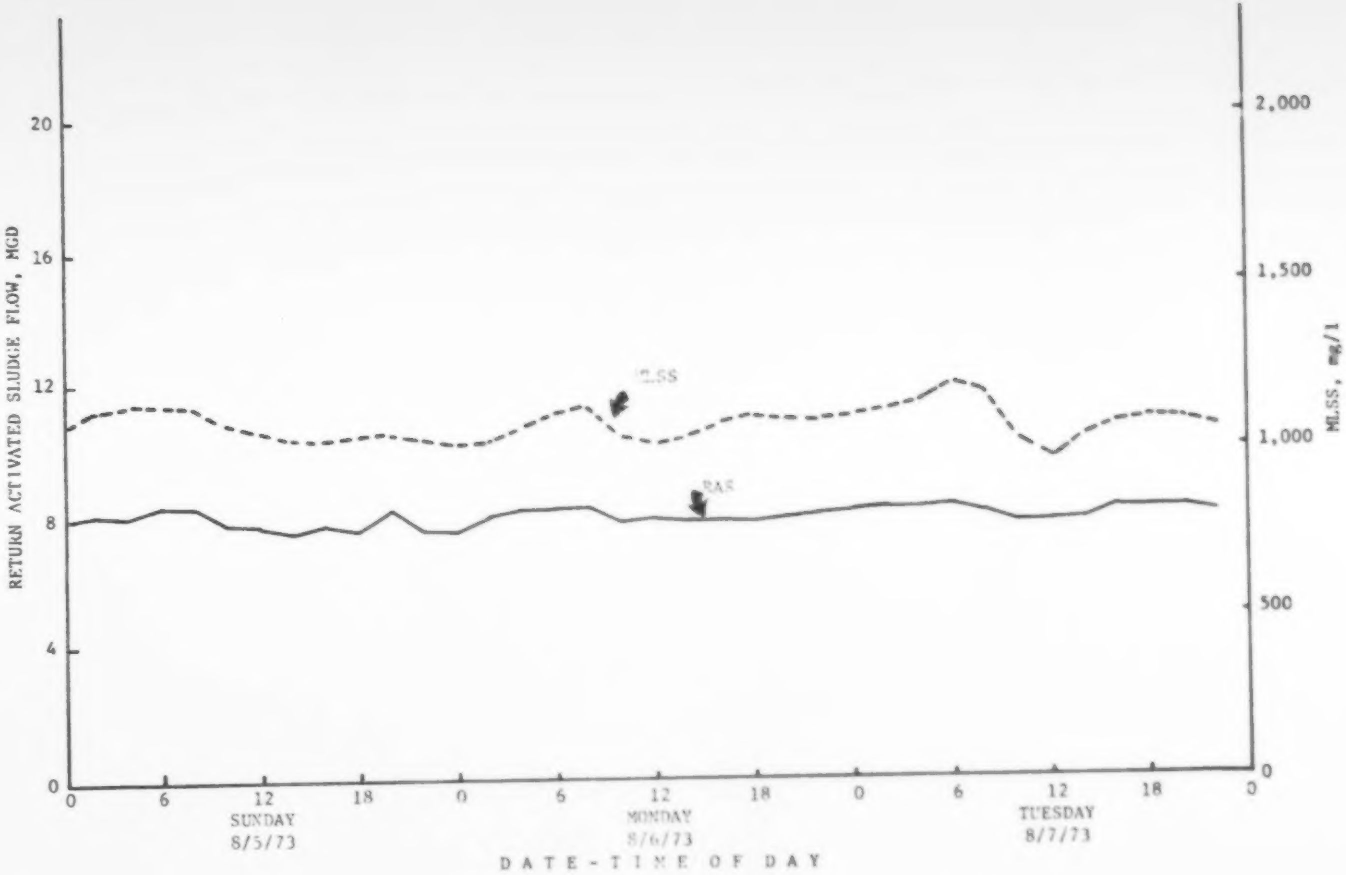


FIGURE 25. MANUAL TEST I: MLSS AND RAS VS. TIME

the secondary process respiration rate as measured by the total air supplied to the aerators.

The Air/RAS controller had two major tasks to achieve:

- Estimate food-uptake-rate from measurements of aeration air flow
- Keep F/M at the setpoint level of 0.33 $\text{days}^{-1}$.

Figure 26 illustrating actual and estimated food uptake indicates that the first task was accomplished successfully. Actual food uptake is taken as the product of primary effluent $BOD_5$ concentration and the volumetric plant flow (assuming neglible soluble $BOD_5$ in the effluent). Estimated food uptake was calculated using air flow rate in the equation developed in Appendix Section B.2. It is apparent from Figure 26 that if the air flow rate is used in this manner, it provides an excellent respirometry measure of plant $BOD_5$ loading.

Figure 27 and 28 are time-histories of RAS and the resulting MLSS in the aerators for, respectively, the Air/RAS and Manual Test II intensive periods. Using the actual food uptake (calculated as described above) and MLSS measurements, F/M time-histories for the two intensive test periods are plotted in Figure 29. The F/M ratio, U, as used here is:

$$U = \frac{Q\, S_{pe}}{(V_a + V_c)\, X f_v} \qquad (23)$$

where $S_{pe}$ is the primary effluent $BOD_5$ concentration, X is MLSS concentration, and the other terms are defined in the Abbreviations and Symbols.

Both F/M time histories exhibit considerable variation about the desired set-point value. This is a result of large and rapid variations in food loading, and therefore, in food uptake, compared to the small changes in MLSS. Figure 27 shows that the Air/RAS control algorithm attempted to vary the MLSS over the entire RAS pumping range of 20 MGD (0.075 $Mm^3$/day) and 8 MGD (0.03 $Mm^3$/day). That pumping range was not sufficient, however, to completely overcome the large concentration inertia inherent in this system because of the large mass of microorganisms in the aerator tanks.

There was, in any event, some improvement attributable to the Air/RAS controller since the late morning peak in F/M, apparent in the manual results, was eliminated. The peak occurred as a consequence of a sharply increased flow which washes out the aerator solids, while at the same time transporting into the aerator a large new quantity of food material. The Air/RAS controller was able to compensate to a limited extent by drawing on the sludge that had accumulated in the clarifiers during the low RAS flow the previous night.

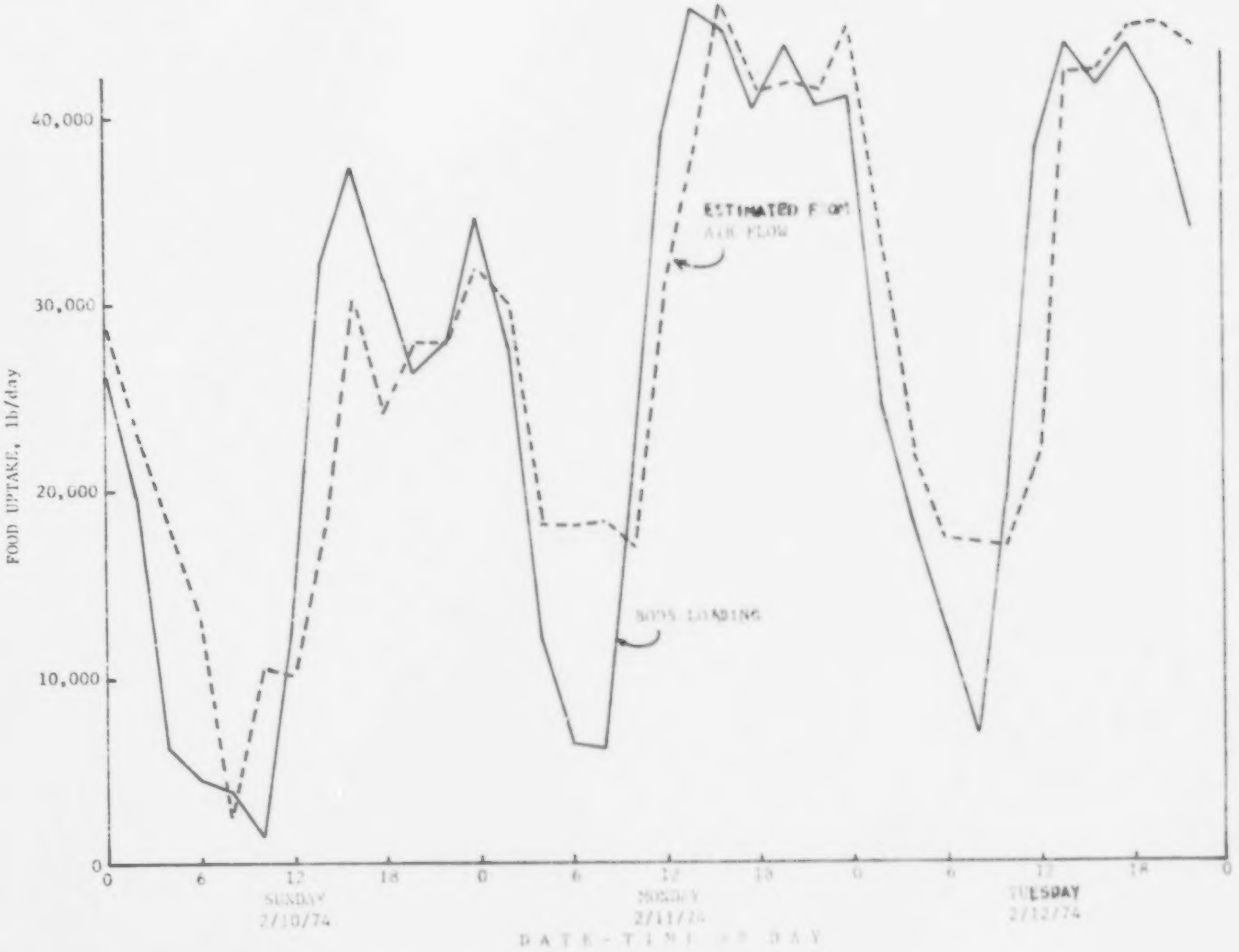


FIGURE 26. AIR/RAS CONTROLLER: ACTUAL AND ESTIMATED FOOD UPTAKE

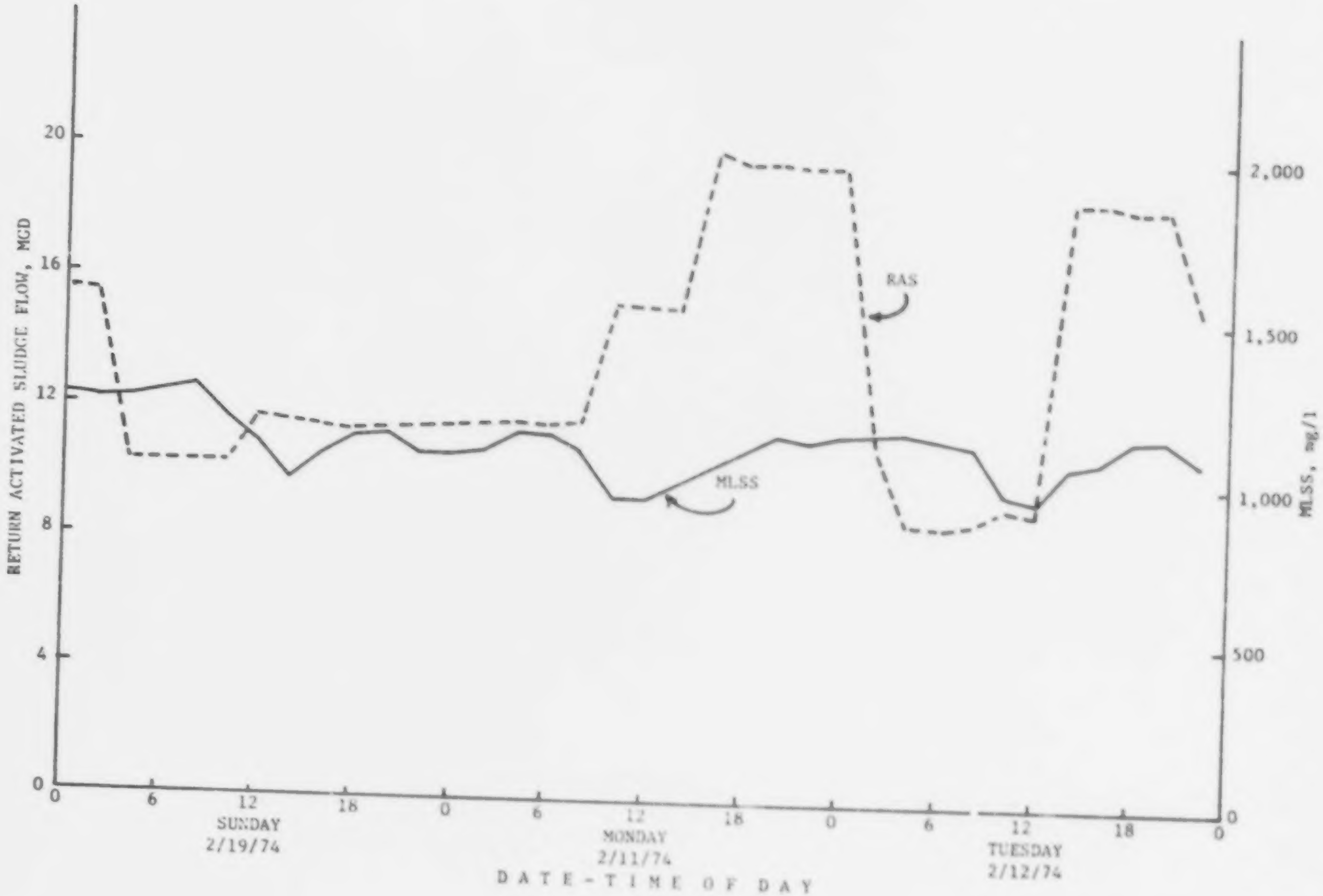


FIGURE 27. AIR/RAS CONTROLLER: MLSS AND RAS VS. TIME

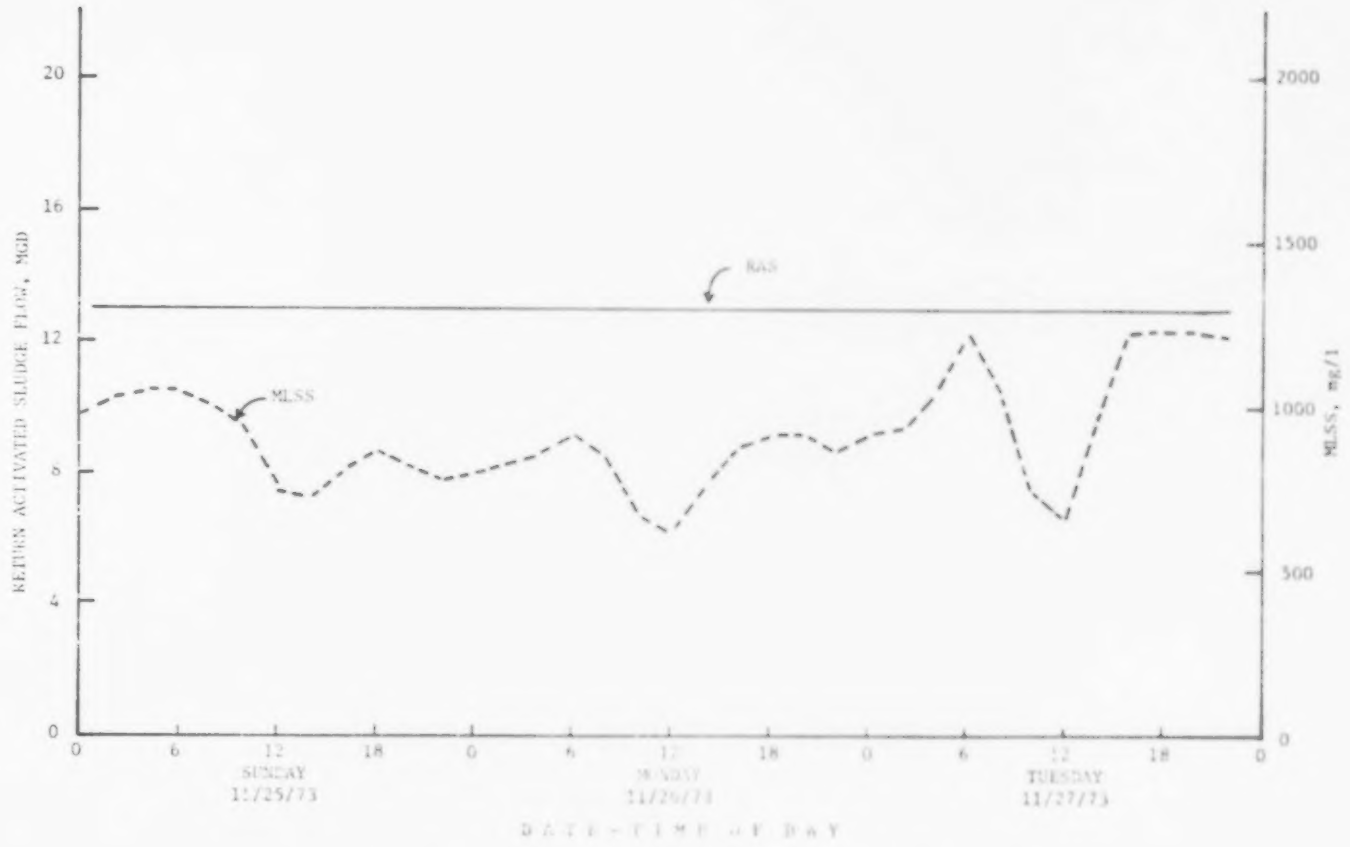


FIGURE 28. MANUAL TEST II: MLSS AND RAS VS. TIME

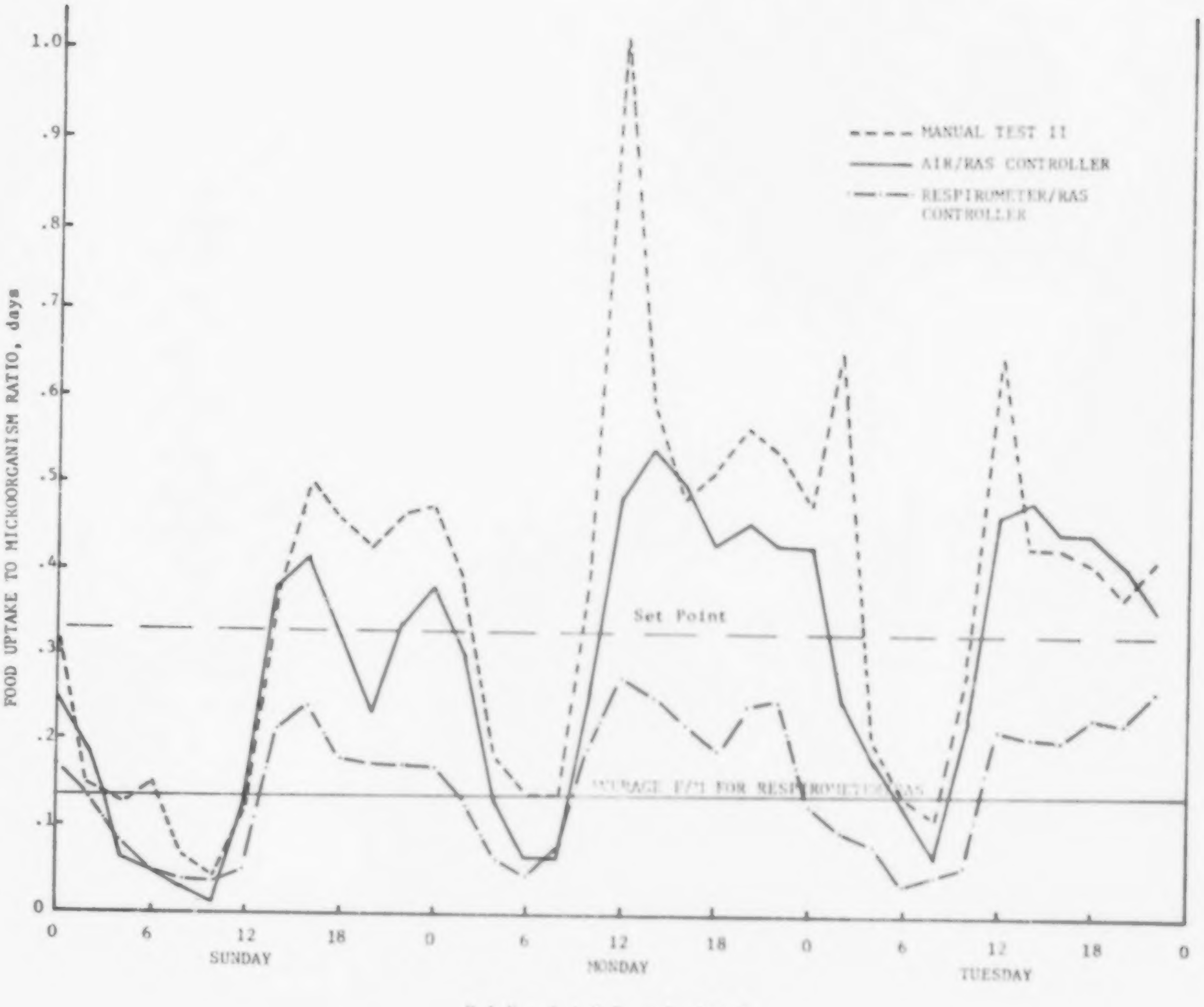


FIGURE 29. COMPARISON OF AMNUAL VS. AUTOMATIC CONTROL OF F/M

The clarifier storage potential was not sufficient, however, to meet the prolonged, high, daytime food demands as can be seen by the excursions of F/M above setpoint. Provision for additional, aerated, sludge storage is necessary to implement a full-time F/M ratio controller adequately, as is discussed in the chapter on algorithm design. Separate sludge storage, however, requires that more detailed consideration be given such process variables as sludge age, wasting rate control, and clarifier sludge accumulation. Answers to these questions could not be adequately furnished by this demonstration, and the previously mentioned difficulties with separate sludge storage in the contact stabilization configuration were a consequence.

Reference to Table 9 for comparison of the secondary treatment efficiencies from the Air/RAS comparison to the Manual II test results reveals a drop for three of the four measured efficiencies with Air/RAS control. Only $BOD_5$ removal efficiencies are close enough to be considered statistically the same.

Figure 30 and 31 illustrating absolute values of secondary effluent BOD and SS concentrations indicate much less variation in mean removals between Air/RAS and Manual II than might be expected from the secondary removal efficiency comparison. In a similar vein, the overall plant removal efficiencies are practically the same for TOC, COD, and SS, while $BOD_5$ is significantly better for the Air/RAS controller.

A probable explanation for the anomaly of low, Air/RAS secondary removal efficiencies is the relatively low, average, secondary unit loading for that period as shown in Table 11. For a given, average, food to microorganism ratio, the average secondary effluent quality in absolute terms is fixed by biological activity constraints and is reasonably constant. Therefore, if the influent contains less food material (i.e., lower loading), the effective efficiency is reduced. During the Air/RAS test period, there was above average removal efficiency for all materials in the primary treatment while in the Manual II period the primary efficiency is below average. The result was an across-the-board, lower, relative secondary unit loading for the Air/RAS period which, for the reasons cited above, could well account for lower observed removal efficiencies.*

Overall, the removal efficiency of the Air/RAS form of F/M controller was apparently slightly worse than for the comparable manual period. There is, however, some question as to the finality of this conclusion for the following reasons:

*The earlier efficiency comparisons for the dry season tests are more reliable since loading differences between tests were less, and were not uniformly either higher or lower for the four measured quality variables.

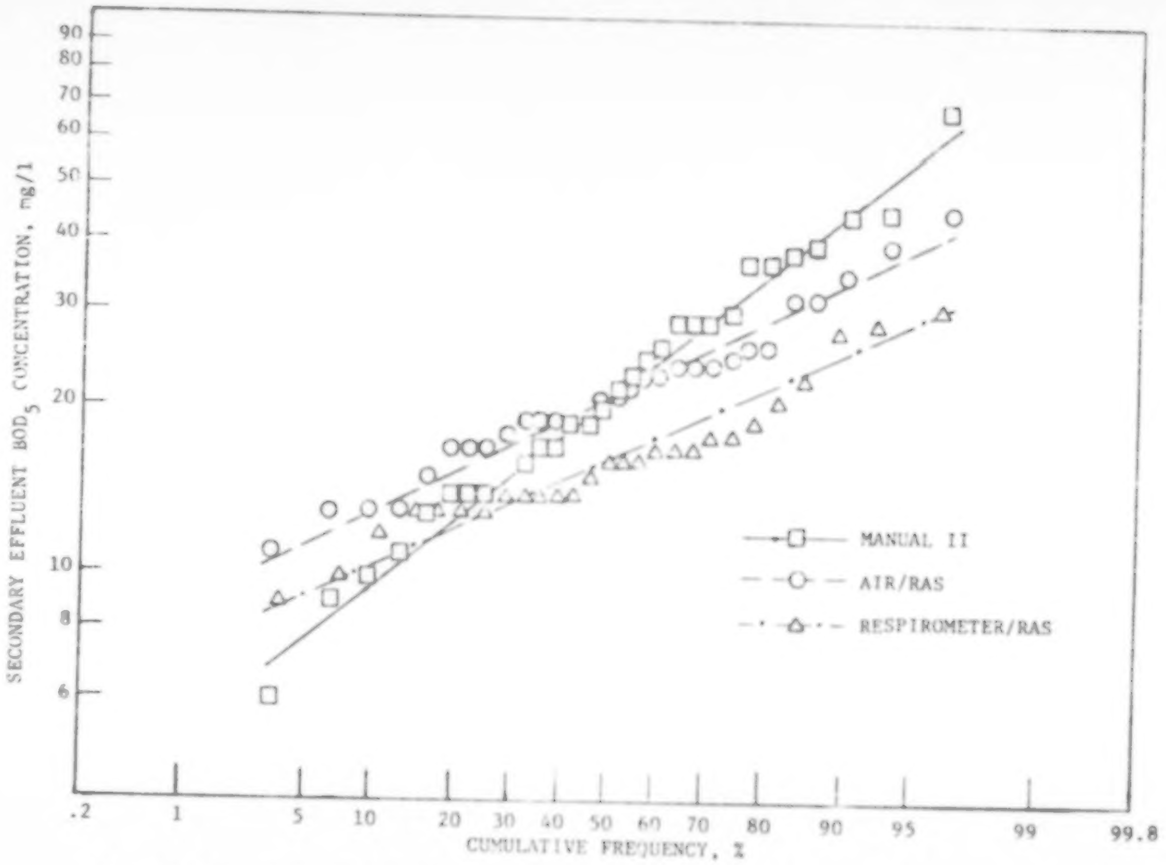


FIGURE 30. WET SEASON TEST: SECONDARY EFFLUENT BOD$_5$ CONCENTRATION VS. LOG-NORMAL FREQUENCY DISTRIBUTION

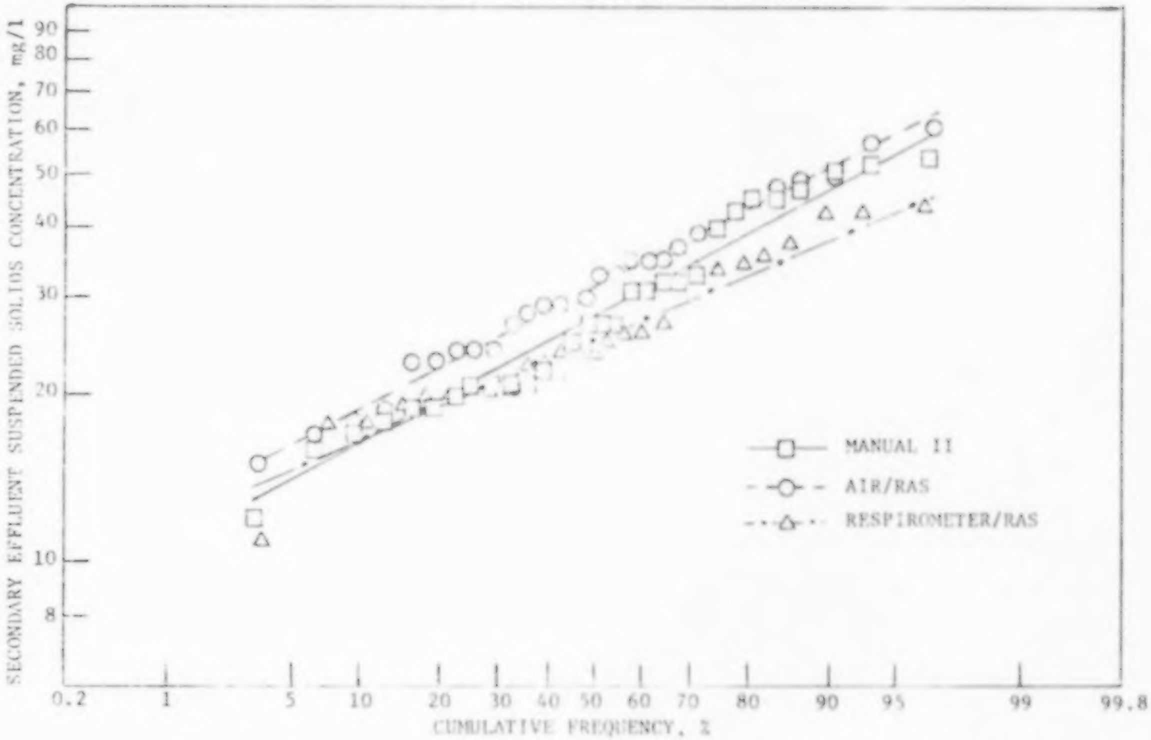


FIGURE 31. WET SEASON TEST: SECONDARY EFFLUENT SUSPENDED SOLIDS CONCENTRATION VS. LOG-NORMAL FREQUENCY DISTRIBUTION

- A large variation in secondary treatment loadings between test periods that could adversely affect Air/RAS results

- Palo Alto Plant design constraints on implementation of the Air/RAS controller did not allow adequate, separate, sludge storage necessary for the controller to maintain a really tight F/M

Table 11. AERATOR LOADING FOR THIS STUDY'S SIX TEST PERIODS

| Test | Aerator loadings, lb/1000 $ft^3$ day SS | BOD | TOC | COD |
|---|---|---|---|---|
| Manual I | 21.9 | 34.1 | 23.9 | 62.9 |
| DO | 18.9 | 39.3 | 21.4 | 58.9 |
| MLSS | 20.1 | 35.0 | 21.8 | 55.8 |
| Manual II | 18.5 | 38.4 | 17.5 | 52.3 |
| Air/RAS | 15.3 | 31.6 | 13.0 | 41.2 |
| Respirometer/RAS | 15.7 | 21.43 | 12.3 | 42.2 |

Further testing is needed before dismissing the possibility for effluent quality improvement using Air/RAS control.

Table 10, reveals the yearly dollar aeration cost for Air/RAS as similar to that for analog man in the loop DO control (Manual II). Air usage, for practical purposes, was the same for both tests. As mentioned in the discussion of the DO controller results, however, the operators effectively maintained a constant DO level during the Manual II test without computer commands. The original, fixed-schedule, air-blowing rate of Manual I was not followed since the compressor power-cost savings attributable to DO had already been demonstrated.

## RESPIROMETER/RAS CONTROLLER

This variation of F/M regulation obtained a direct measurement of oxygen uptake (respiration rate) from a sample of aerator mixed liquor and, from that measurement, inferred the food loading in the secondary process. RAS flow was then set based on the suspended solids level necessary to maintain an instantaneous F/M value at or below the desired set-point value of 0.33 $days^{-1}$.

Figure 32 illustrates results for the first performance task of the Respirometer/RAS controller, estimating food uptake. Here, as in the Air/RAS discussion, actual food uptake is represented by the product of primary effluent $BOD_5$ concentration and volumetric plant flow. Estimated food uptake was calculated from the respirometer's oxygen uptake reading according to the formula developed in Appendix B.5. Diurnal variations of the same periodicity occured in both actual and estimated food uptake, but the estimate based on respiration rate lags the actual uptake and is also attenuated in amplitude. Part of the lag is attributable to the one-hour sample-processing time of the respirometer. The remainder of the lag, plus the amplitude attenuation, are probably attributable to the following:

- Transport lag within the aerators - Less than theoretically perfect mixing causes a lag between waste concentrations at the influent point versus the effluent point where respirometer sample was taken.

- Biological uptake lag - Actual biological oxidation of material occurs only after the occurrence of all preceding lags associated with diffusion of substrate into the cell and conversion of nonsoluble materials to usable soluble substances. This process also has an averaging effect that attenuates peak variations in substrate utilization when compared to food-input variations.

An interesting implication of the less variable food utilization (when compared to aerator loading) for fully mixed operation is that there is probably less necessity for tight, instantaneous, F/M control based on food loading. If F/M control based on utilization is considered instead, much less diurnal variation would be observed since the volume of biological processes tend to smooth out the food loading peaks to some extent. Of course, there still are significant remaining variations in F/M, even based on actual food utilization; therefore, F/M control is still a desirable objective.

Figure 33 shows the RAS flow and resultant MLSS for the Respirometer/RAS intensive test period. Note that there were comparatively modest changes in MLSS. As mentioned in the Air/RAS controller results, lack of sufficient sludge storage capacity and limitations on RAS pumping rates (especially the low limit which prevented some additional accumulation of sludge in the clarifiers at night) made improved MLSS control impossible.

Resultant diurnal variation in F/M for the Respirometer/RAS controller is compared to Manual II and Air/RAS results in Figure 29. The sludge retention time of the secondary process was changed during the respirometer/RAS control evolution because of the demands by the plant's thickeners for less wasting of the mixed liquor. This change increased the reactor clarifiers solids inventory and affected the F/M set-point. Thus, while the computer was set to control at a set-point of F/M = .33 $day^{-1}$, the plant actually operated a lower average F/M as shown in

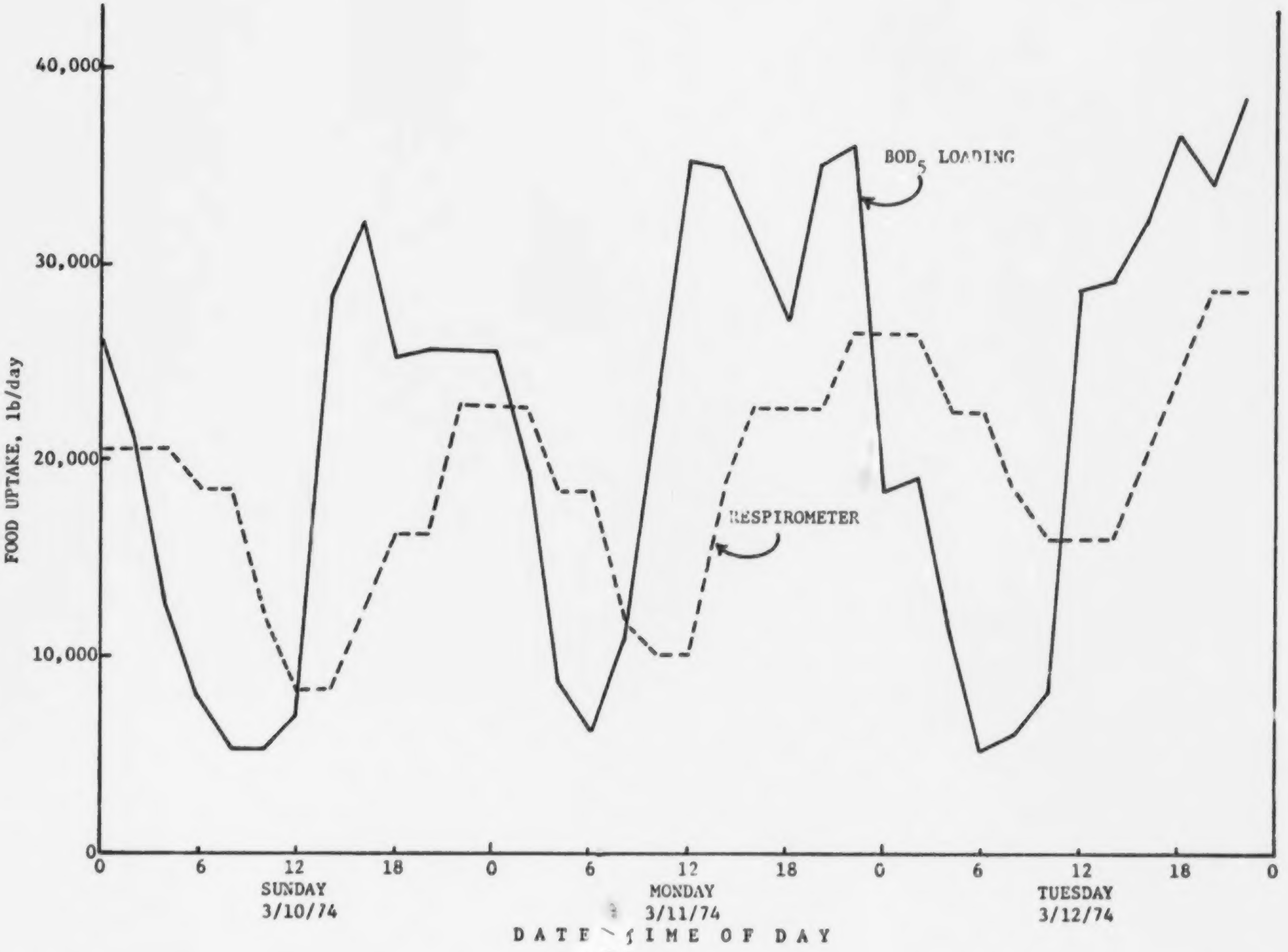


FIGURE 32. RESPIROMETER/RAS CONTROLLER: ACTUAL VS. ESTIMATED FOOD UPTAKE

Figure 29 and did not control to set-point. The F/M ratio was kept below setpoint at all times, as was desired. Also, as was the case with the Air/RAS, the late morning peaks in F/M on Monday and Tuesday were essentially eliminated.

The point of keeping F/M constant was to reduce the diurnal variability of effluent quality. Listed below are bi-hourly means and standard deviations of secondary effluent concentrations of the quality measurements for the 3 day intensive test periods. The relative variability is the standard deviation divided by the mean.

Three Day Intensive Test Results for Secondary Effluent

| | Respirometer/RAS | | | Manual II | | |
|---|---|---|---|---|---|---|
| | mean | standard deviation | relative variability | mean | standard deviation | relative variability |
| SS,mg/l | 31.3 | 9.4 | 30% | 20.3 | 7.4 | 37% |
| BOD,mg/l | 12.1 | 4.1 | 34% | 8.7 | 4.2 | 48% |
| TOC,mg/l | 18.4 | 2.9 | 16% | 19.6 | 3.5 | 18% |
| COD,mg/l | 72.4 | 9.8 | 14% | 58.8 | 10.0 | 17% |

In all cases except SS, the absolute standard deviation in daily effluent quality is less for the Respirometer/RAS controller. The relative variability (standard deviation divided by the mean) is less in every case for the Respirometer/RAS. Thus, the F/M ratio regulation does exhibit the expected result of reducing diurnal effluent quality swings. The benefit of this result is an overall improvement in effluent quality and removal efficiency.

Table 9 presents the efficiencies for the plant obtained during the Respirometer/RAS test. Compared to Manual II results for (biological) treatment, the Respirometer/RAS showed equal results for $BOD_5$, significantly improved SS removal, slightly better COD, and slightly worse TOC. In the comparison of Respirometer/RAS to Manual II below a negative sign indicates decreased performance for the Respirometer/RAS control when compared to Manual II. The absolute change is defined as the difference between the percent removal efficiencies of the Respirometer/RAS and the Manual II. The change relative to the Manual II is the absolute change divided by the Manual II removal efficiencies.

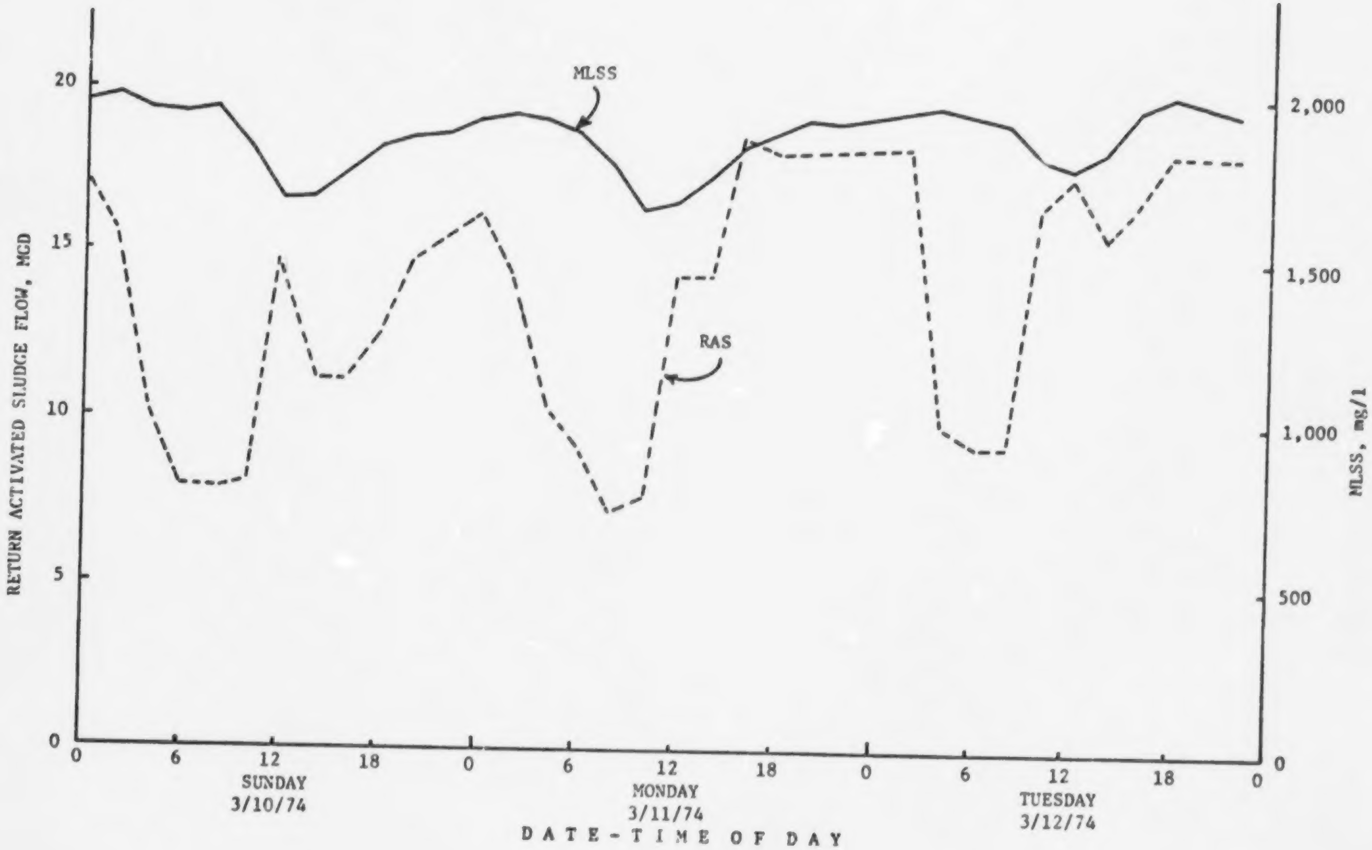


FIGURE 33. RESPIROMETER/RAS CONTROLLER: MLSS AND RAS VS. TIME

| Secondary Efficiency | Absolute Change | Change Relative To Manual II |
|---|---|---|
| SS | + 4.9% | + 8.4% |
| $BOD_5$ | 0.0 | 0.0 |
| TOC | - 4.2% | - 6.2% |
| COD | + 0.8% | + 1.2% |

These removal efficiencies of the biological process in aggregate showed no significant improvement over the manual results, but were achieved for abnormally light loadings in each quantity as indicated in Table 11. The primary process during the Respriometer/RAS operation exhibited unusually efficient performance and thus reduced the loading to the biological reactor. An improved effluent quality occurred during operation with the Respirometer/RAS controller as shown in Figures 30 and 31. Both $BOD_5$ and SS concentrations in the secondary effluent showed reduced means, as well as less dispersion, when compared to Manual II and Air/RAS. Mean values obtained are:

| | Respirometer/RAS | Manual II | Air/RAS |
|---|---|---|---|
| $BOD_5$,mg/l | 16.5 | 21 | 21 |
| SS,mg/l | 25 | 28 | 31 |

Furthermore, the total removal efficiencies of the plant when it was under Respirometer/RAS control (Table 9) were the highest for any test period for the entire demonstration. Total plant efficiency improvements from Manual II to Respirometer/RAS were:

| Plant Total Efficiency, | Absolute Change | Change Relative to Manual II |
|---|---|---|
| SS | + 4.0% | + 5.0% |
| $BOD_5$ | + 10.5% | + 12.9% |
| TOC | + 3.7% | + 5.2% |
| COD | + 2.2% | + 2.9% |

In total then, there was demonstrable positive improvement in effluent quality during operation with the Respirometer/RAS F/M controller. The improvement, however, was probably not related only or even chiefly to the application of respirometer/RAS control. During this control test, the changes in the plant wasting, at the request of the City of Palo Alto, increased the solids inventory in the biological process compared to that during all other operation. The increased inventory produced significantly lower average operating F/M. The combination of improved primary performance and the lower average F/M in the biological process undoubtedly contributed significantly to the observed improved overall plant performance. While the operation with Respirometer/RAS control exhibited the smallest variability in the instantaneous F/M, further work is needed to assess whether this reduced variability in the F/M significantly contributed to the observed improvement in plant performance.

From Table 10 the yearly aeration cost increase of Respirometer/RAS over Manual II (analog man in the loop DO control) was \$3,583. The air figure has been corrected for the period from February 20 to 27 in which the DO setpoint was at 2.0 mg/1, and extra air was required compared to operation at the normal 0.75 mg/1 setpoint. Still, there was a substantial increase in usage per pound of $BOD_5$ loading in the aerator which caused the aeration cost increase. Operation of the plant at the significantly lower average F/M of approximately 0.15 $gmBOD_5$/gmMLVSS/day increased the air requirements through increased endogenous respiration of the sludge mass. A revised net cost increase from Manual II to Respirometer/RAS test is then only \$1,852. (operation at significantly lower F/M (higher MLVSS) increases air requirements through increased endogenous respiration of this sludge mass.)

# REFERENCES

1. Martin, C. F., J. F. Petersack, and R. G. Smith, Palo Alto Wastewater Treatment Plant Automation Project, May 1974.

2. Wells, C. H., Phase I Report Palo Alto Wastewater Treatment Plant Automation Project, Process Control Descriptions, Report for California State WQCB by Systems Control, Inc., May 1973.

3. Petersack, J. F. and C. F. Martin, Phase I Report Palo Alto Wastewater Treatment Plant Automation Project Task 2: Experiment Design, prepared for State of California Water Quality Control Board by Systems Control, Inc., July 1973.

4. Petersack, J. F., R. G. Smith, J. J. Ogan, Palo Alto Wastewater Treatment Plant Automation Project Task 3: Development of Methodology, Report for State of California Water Quality Control Board by Systems Control, Inc., February 1974.

5. Operation and Maintenance Manual, City of Palo Alto Water Quality Control Plant, November 1971.

6. American Public Health Association, Standard Methods for the Examination of Waste Water - 13th Edition, 1971.

7. Metcalf & Eddy, Inc., Wastewater Engineering, McGraw-Hill Book Company New York 1972.

8. Hawkes, H.A., The Ecology of Waste Water Treatment, Macmillan Company, New York 1963.

9. Iroshoff, Karl, W. J. Miiller, and D. K. B. Thistlethwayte, Disposal of Sewage and Other Water-Bome Wastes, Ann Arbor Science Publishers, Inc., (Ann Arbor) 1971.

10. Bolton, R. L., and L. Klein, Sewage Treatment: Basic Principles and Trends, Ann Arbor Science Publishers, Inc., (Ann Arbor) 1971.

11. Roesler, J. A., The Effect of Automatic Dissolved Oxygen Control on the Performance of the Activated Sludge Process, Environmental Protection Agency Report from the Advanced Waste Treatment Research Laboratory, (Cincinnati, Ohio) 1974.

12. Smith, Robert, Electrical Power Consumption for Municipal Wastewater Treatment, Environmental Protection Agency Report EPA-R2-73-281, July 1973.

## REFERENCES (Continued)

13. Gandy, Anthony F., Jr. and Elizabeth T. Gandy, Biological Concepts for Design and Operation of the Activated Sludge Process, Report for the Environmental Protection Agency by Oklahoma State University, Project #17090 FQJ, September 1971.

14. Petersack, J. F., and D. E. Stepner, "Computerized Data Management and Control of a Secondary Wastewater Treatment Plant," presented at the International Association on Water Pollution Conference, (London, England) September 1973.

# SECTION X

## GLOSSARY

| | |
|---|---|
| $BOD_5$ | Five-day biochemical oxygen demand, mg/l |
| COD | Chemical oxygen demand, mg/l |
| DO | Dissolved oxygen, mg/l |
| $\hat{DO}$ | Mean dissolved oxygen |
| $\dot{DO}$ | 1st derivative at dissolved oxygen |
| $\ddot{DO}$ | 2nd derivative of dissolved oxygen |
| dF/dt | Food uptake rate, mg/l $day^{-1}$ |
| $\hat{f}_\tau$ | Error signal |
| F/M | Food-to-microorganism ratio, gm $BOD_5$/gm MLVSS/day |
| K | GAIN |
| $K_d$ | Microorganism death rate, $days^{-1}$ |
| L | Fraction of original $BOD_5$ remaining in cell material after $BOD_5$ use in cell synthesis |
| MG | Millions of gallons |
| MGD | Millions of gallons per day |
| MLSS | Mixed liquor suspended solids, mg/l |
| Q | Plant flow, MGD |
| $Q_A$ | Air flow, SCFM |
| $Q_{O_2}$ | Oxygen use rate in biological oxidation, SCFM |
| $Q_R$ | RAS flow rate, MGD |
| $Q_W$ | Waste sludge flow rate, MGD |
| R | Respiration rate, mg/l |
| RAS | Return activated sludge |

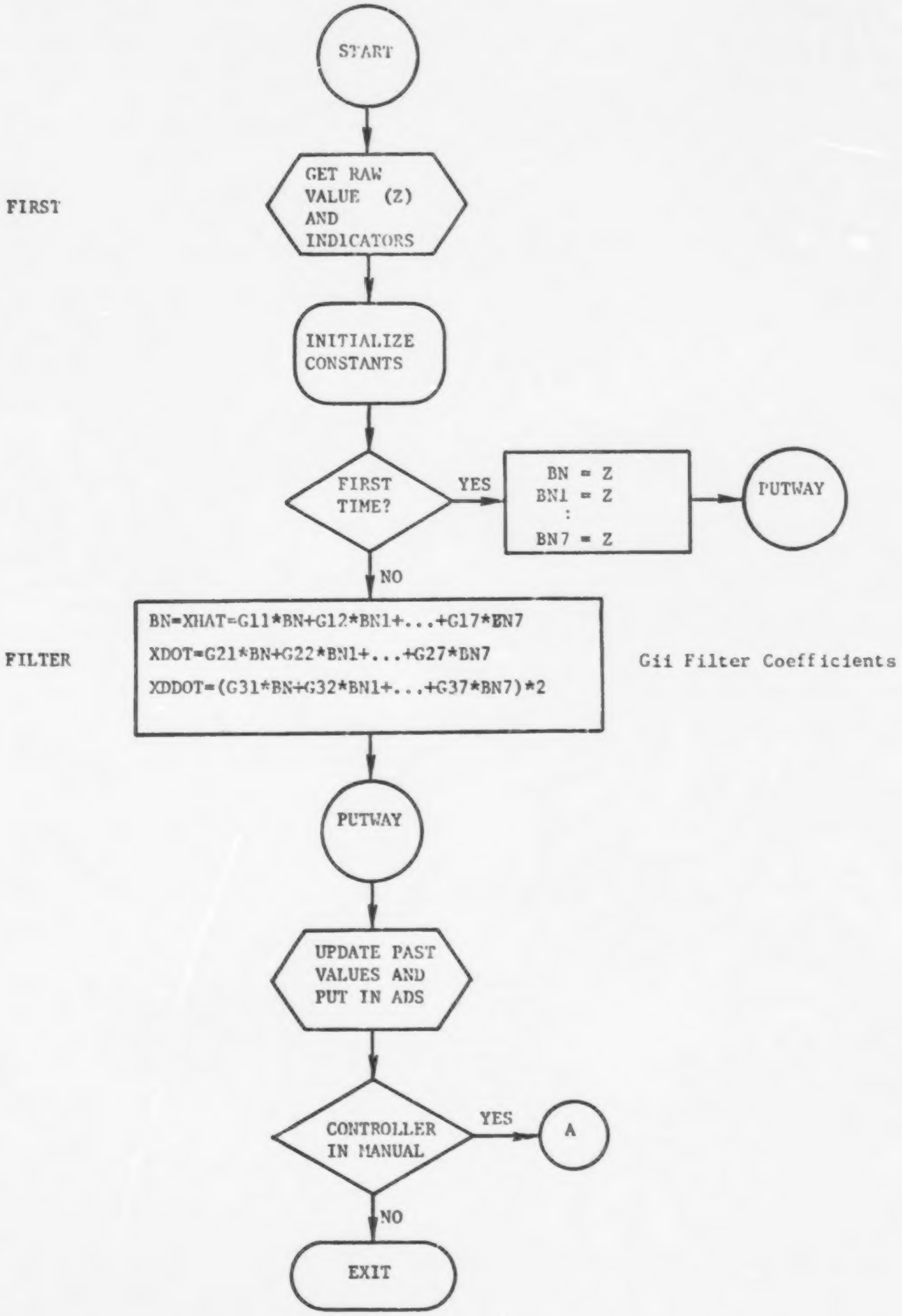
| | |
|---|---|
| $S_o$ | Primary effluent substrate, mg/l |
| $S_a$ | Aerator substrate, mg/l |
| $S_c$ | Clarifier substrate, mg/l |
| SCFM | Standard cubic feet per minute |
| SS | Suspended solids, mg/l |
| T | Time constant |
| t | real time |
| U | Food to microorganism, $day^{-1}$ |
| $\mu$ | Velocity |
| $V_a$ | Aerators volume, mg |
| $V_c$ | Clarifier volume, mg |
| $V_r$ | Respirometer sample-chamber volume, liters |
| WAS | Waste activated sludge |
| $X_a$ | Aerator suspended solids, mg/l |
| $X_c$ | Clarifier suspended solids, mg/l |
| $X_R$ | RAS suspended solids, mg/l |
| Y | Mass yield of microorganisms per unit mass substrate consumed |
| y | $BOD_5$ mass demand equivalent per unit mass of microorganisms |
| $\alpha$ | Constant in DO equation |
| $\Delta$ | Time change in minutes |
| $\theta_c$ | Mean cell residence time of microorganisms in the secondary system |

# APPENDIX A

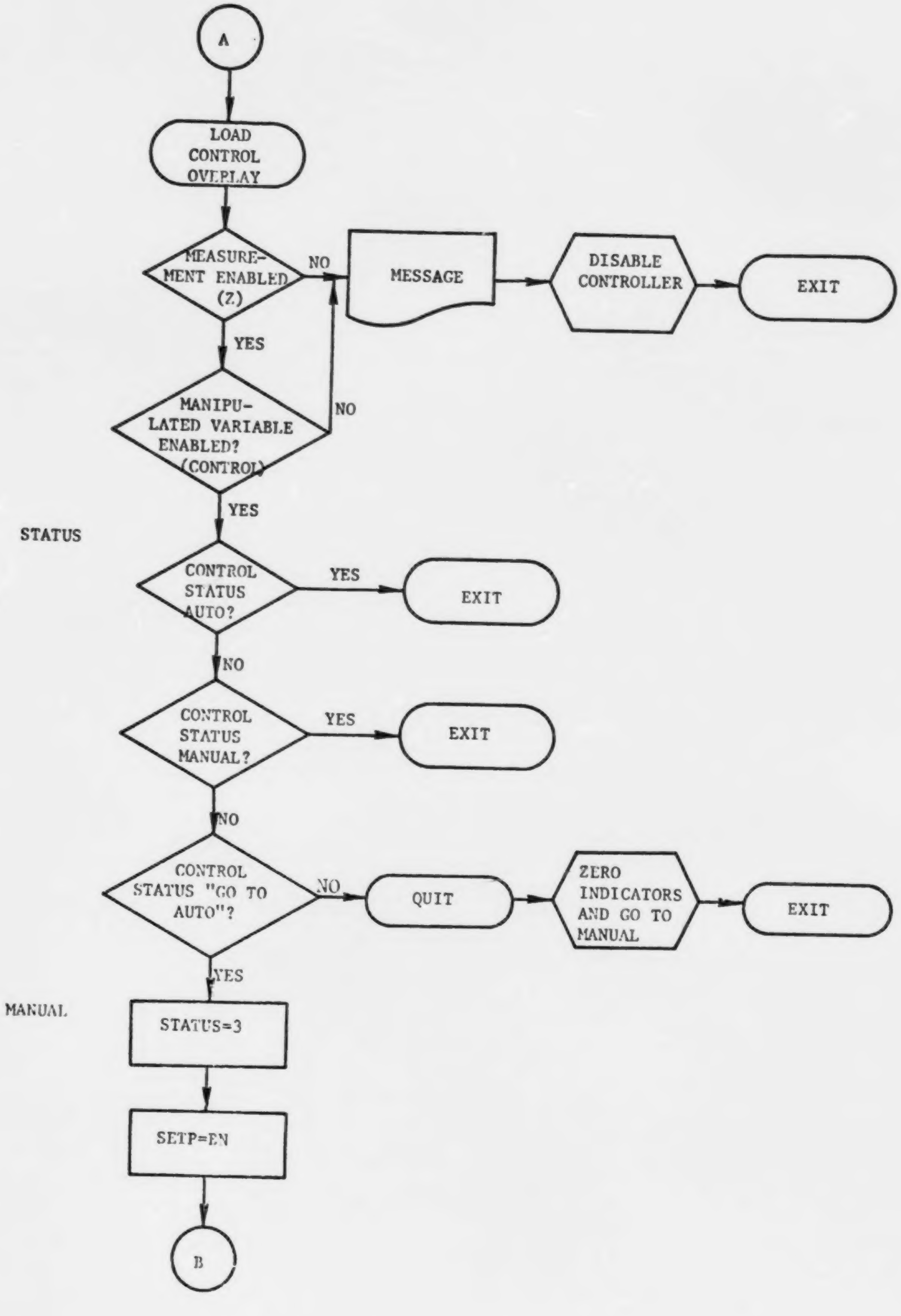
# FLOWCHARTS

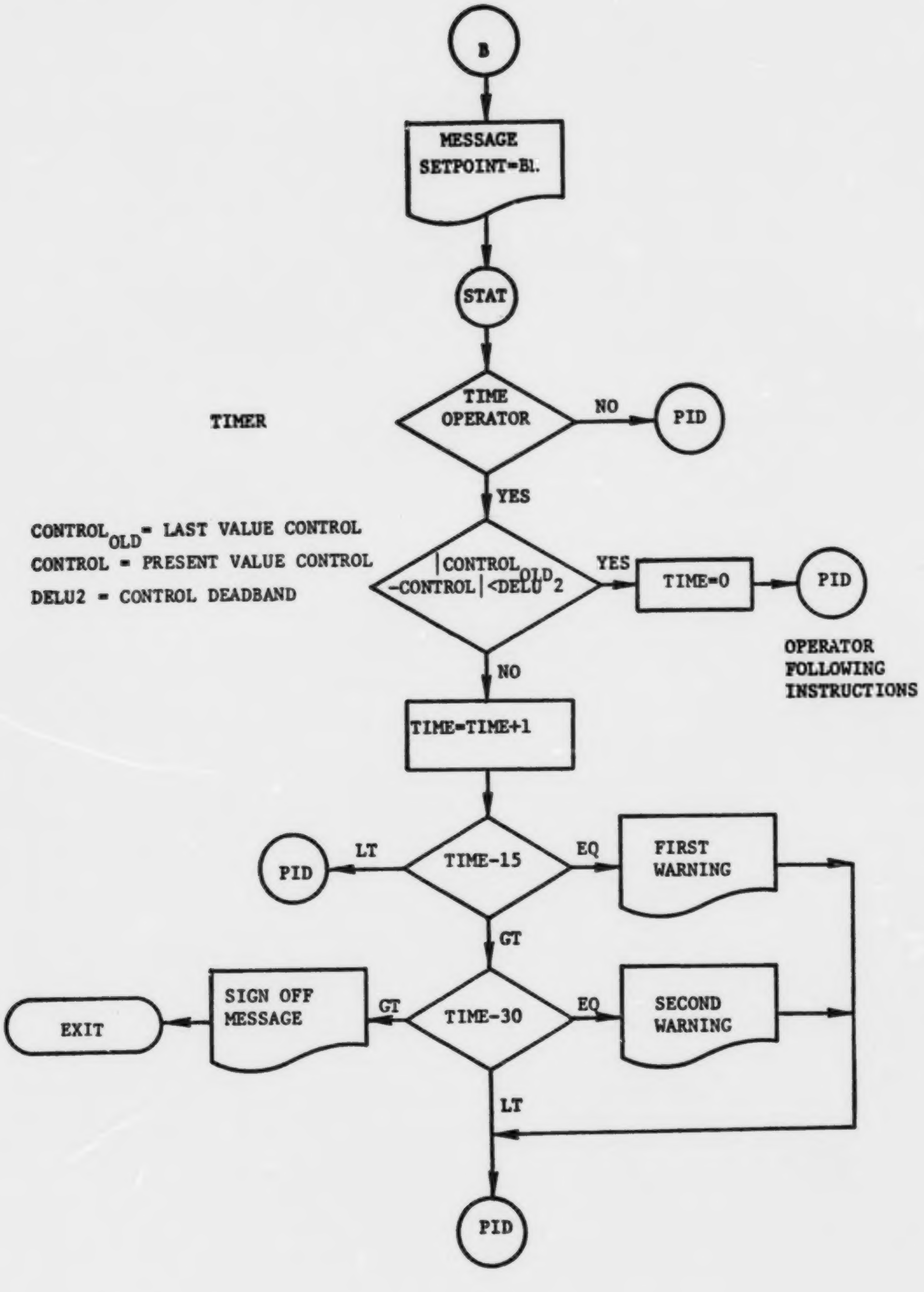
## ASSOCIATED DATA STORAGE (ADS) DATA DEFINITION FOR DO/RAS CONTROL

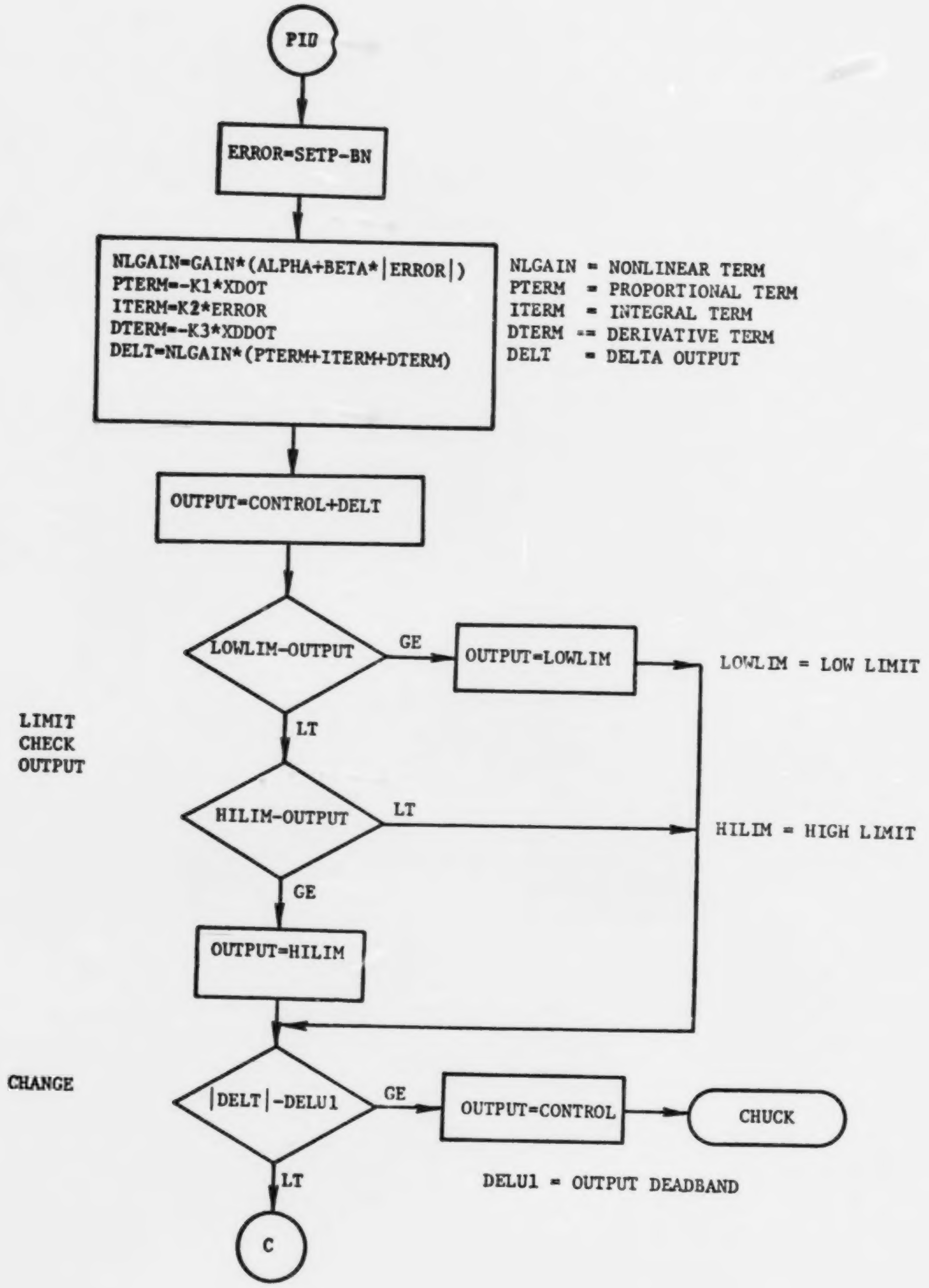
| ADS Number | Variable | Definition |
|---|---|---|
| 1 | C1 | Gain terms |
| 2 | C2 | |
| 3 | C3 | |
| 4 | C4 | |
| 5 | XR | SS in RAS |
| 6 | QRMAX | High limit |
| 7 | QRMIN | Low limit |
| 8 | QTOL | Deadband |
| 9-20 | Not used | |

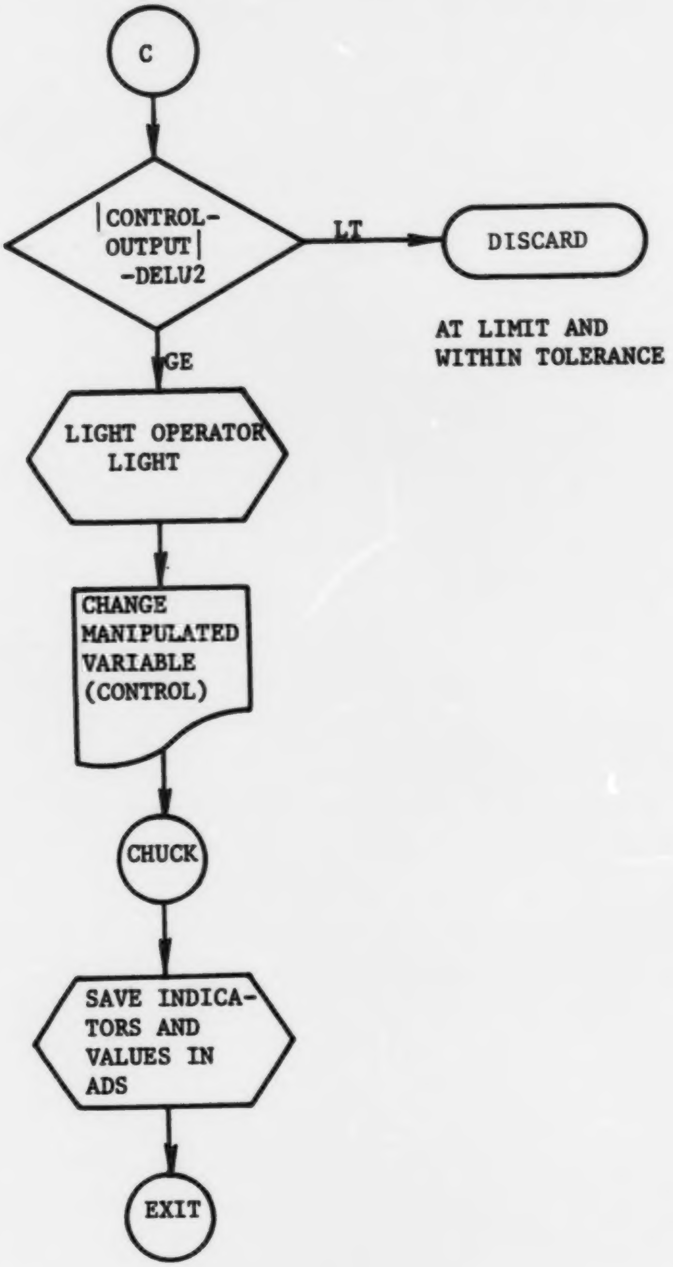

START
FIRST
GET RAW VALUE (Z) AND INDICATORS
INITIALIZE CONSTANTS
FIRST TIME?
YES
BN = Z
BN1 = Z
:
BN7 = Z
PUTWAY
NO
FILTER
BN=XHAT=G11*BN+G12*BN1+...+G17*BN7
XDOT=G21*BN+G22*BN1+...+G27*BN7
XDDOT=(G31*BN+G32*BN1+...+G37*BN7)*2
Gii Filter Coefficients
PUTWAY
UPDATE PAST VALUES AND PUT IN ADS
CONTROLLER IN MANUAL
YES
A
NO
EXIT

DO AND MLSS CONTROL FLOWCHART


A
LOAD CONTROL OVERLAY
MEASUREMENT ENABLED (Z)
NO
MESSAGE
DISABLE CONTROLLER
EXIT
YES
MANIPULATED VARIABLE ENABLED? (CONTROL)
NO
YES
STATUS
CONTROL STATUS AUTO?
YES
EXIT
NO
CONTROL STATUS MANUAL?
YES
EXIT
NO
CONTROL STATUS "GO TO AUTO"?
NO
QUIT
ZERO INDICATORS AND GO TO MANUAL
EXIT
YES
MANUAL
STATUS=3
SETP=EN
B

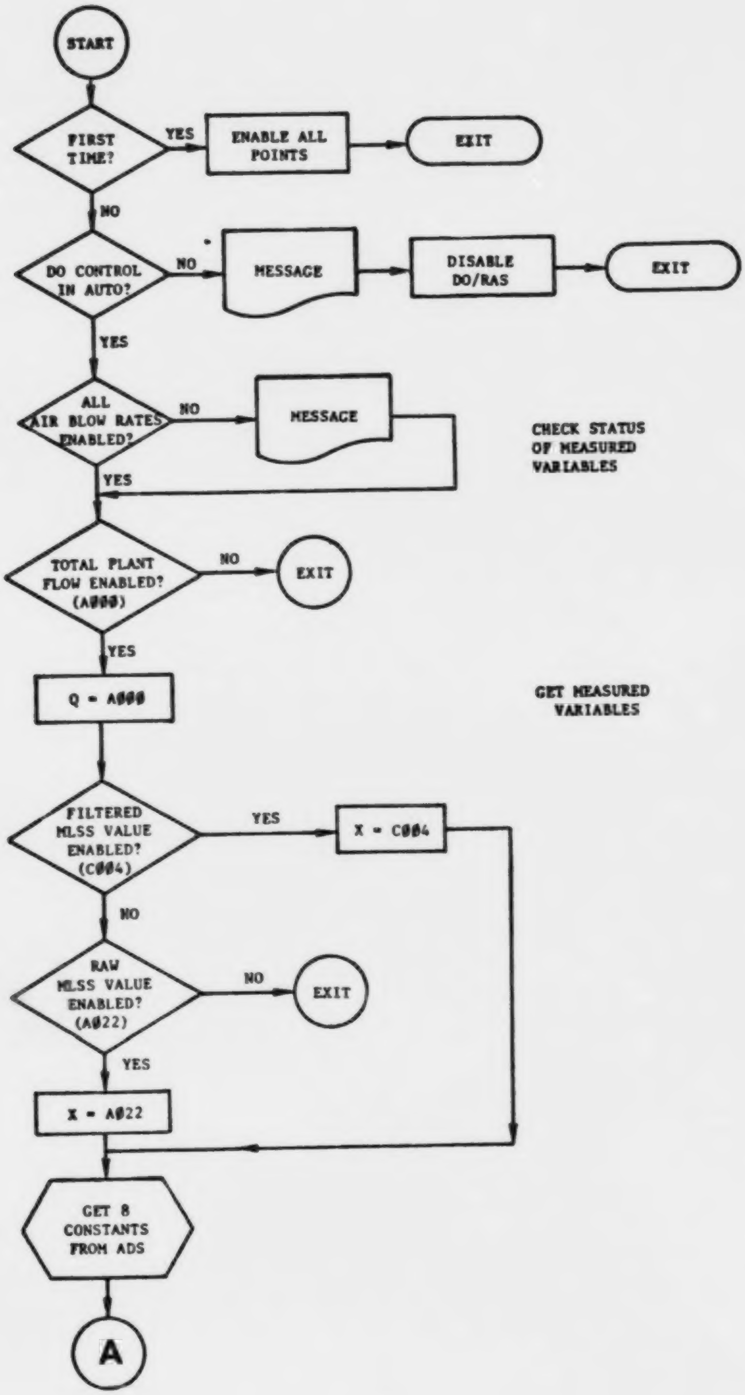

B
MESSAGE SETPOINT=B1.
STAT
TIMER
TIME OPERATOR
NO
PID
YES
CONTROL$_{OLD}$ = LAST VALUE CONTROL
CONTROL = PRESENT VALUE CONTROL
DELU2 = CONTROL DEADBAND
|CONTROL$_{OLD}$ -CONTROL| <DELU2
YES
TIME=0
PID
OPERATOR FOLLOWING INSTRUCTIONS
NO
TIME=TIME+1
PID
LT
TIME-15
EQ
FIRST WARNING
GT
EXIT
SIGN OFF MESSAGE
GT
TIME-30
EQ
SECOND WARNING
LT
PID


PID
ERROR=SETP-BN
NLGAIN=GAIN*(ALPHA+BETA*|ERROR|)
PTERM=-K1*XDOT
ITERM=K2*ERROR
DTERM=-K3*XDDOT
DELT=NLGAIN*(PTERM+ITERM+DTERM)
NLGAIN = NONLINEAR TERM
PTERM = PROPORTIONAL TERM
ITERM = INTEGRAL TERM
DTERM = DERIVATIVE TERM
DELT = DELTA OUTPUT
OUTPUT=CONTROL+DELT
LOWLIM-OUTPUT
GE
OUTPUT=LOWLIM
LOWLIM = LOW LIMIT
LT
LIMIT
CHECK
OUTPUT
HILIM-OUTPUT
LT
HILIM = HIGH LIMIT
GE
OUTPUT=HILIM
CHANGE
|DELT|-DELU1
GE
OUTPUT=CONTROL
CHUCK
DELU1 = OUTPUT DEADBAND
LT
C

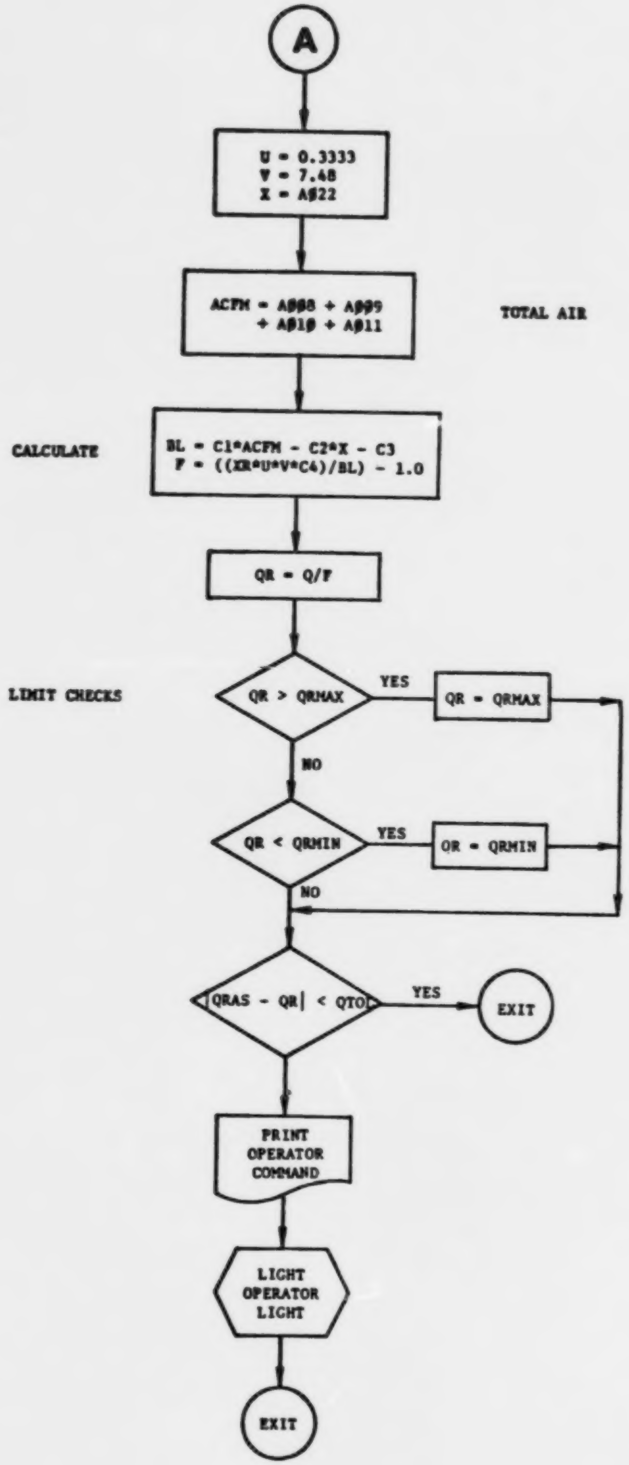

C
|CONTROL-
OUTPUT|
-DELU2
LT
DISCARD
AT LIMIT AND
WITHIN TOLERANCE
GE
LIGHT OPERATOR
LIGHT
CHANGE
MANIPULATED
VARIABLE
(CONTROL)
CHUCK
SAVE INDICA-
TORS AND
VALUES IN
ADS
EXIT

## ASSOCIATED DATA STORAGE (ADS) DATA DEFINITION FOR DO AND MLSS CONTROL

| ADS NUMBER | VARIABLE | DEFINITION |
|---|---|---|
| 1 | SETP | SETPOINT |
| 2 | GAIN | LOOP GAIN |
| 3 | K1 | PROPORTIONAL GAIN |
| 4 | K2 | INTEGRAL GAIN |
| 5 | K3 | DERIVATIVE GAIN |
| 6 | TIME | TIME SINCE LAST CHANGE |
| 7 | BN | FILTERED VALUE |
| 8 | BN1 | PREVIOUS VALUE (n-1) |
| 9 | BN2 | PREVIOUS VALUE (n-2) |
| 10 | BN3 | PREVIOUS VALUE (n-3) |
| 11 | BN4 | PREVIOUS VALUE (n-4) |
| 12 | BN5 | PREVIOUS VALUE (n-5) |
| 13 | BN6 | PREVIOUS VALUE (n-6) |
| 14 | BN7 | PREVIOUS VALUE (n-7) |
| 15 | XDOT | DERIVATIVE OF BN |
| 16 | XDDOT | SECOND DERIVATIVE OF BN |
| 17 | OUTPUT | Δ OUTPUT |
| 18 | ALPHA | NONLINEAR GAINS |
| 19 | BETA | |
| 20 | NOT USED | |

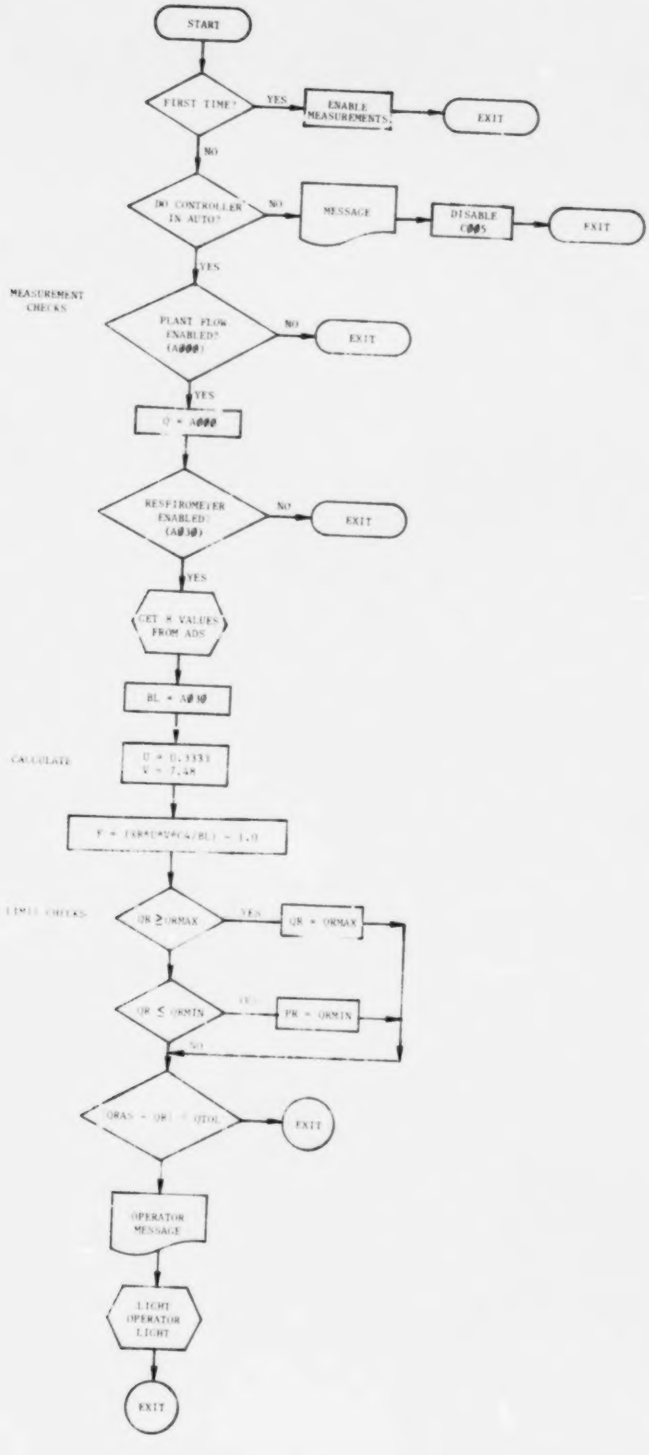

START
FIRST TIME?
YES
ENABLE ALL POINTS
EXIT
NO
DO CONTROL IN AUTO?
NO
MESSAGE
DISABLE DO/RAS
EXIT
YES
ALL AIR BLOW RATES ENABLED?
NO
MESSAGE
CHECK STATUS OF MEASURED VARIABLES
YES
TOTAL PLANT FLOW ENABLED? (A000)
NO
EXIT
YES
Q = A000
GET MEASURED VARIABLES
FILTERED MLSS VALUE ENABLED? (C004)
YES
X = C004
NO
RAW MLSS VALUE ENABLED? (A022)
NO
EXIT
YES
X = A022
GET 8 CONSTANTS FROM ADS
A

DO/RAS CONTROL FLOWCHART


A
U = 0.3333
V = 7.48
X = A022
ACFM = A008 + A009
+ A010 + A011
TOTAL AIR
CALCULATE
BL = C1*ACFM - C2*X - C3
F = ((XR*U*V*C4)/BL) - 1.0
QR = Q/F
LIMIT CHECKS
QR > QRMAX
YES
QR = QRMAX
NO
QR < QRMIN
YES
QR = QRMIN
NO
|QRAS - QR| < QTO
YES
EXIT
PRINT
OPERATOR
COMMAND
LIGHT
OPERATOR
LIGHT
EXIT

## ASSOCIATED DATA STORAGE (ADS) DATA DEFINITION FOR DO/RAS CONTROL

| ADS NUMBER | VARIABLE | DEFINITION |
|---|---|---|
| 1 | C1 | GAIN TERMS |
| 2 | C2 | |
| 3 | C3 | |
| 4 | C4 | |
| 5 | XR | SS IN RAS |
| 6 | QRMAX | HIGH LIMIT |
| 7 | QRMIN | LOW LIMIT |
| 8 | QTOL | DEADBAND |
| 9-20 | NOT USED | |


START
FIRST TIME?
YES
ENABLE MEASUREMENTS
EXIT
NO
DO CONTROLLER IN AUTO?
NO
MESSAGE
DISABLE C005
EXIT
YES
MEASUREMENT CHECKS
PLANT FLOW ENABLED? (A000)
NO
EXIT
YES
Q = A000
RESPIROMETER ENABLED? (A030)
NO
EXIT
YES
GET # VALUES FROM ADS
BL = A030
CALCULATE
U = 0.3331
V = 7.48
F = (XR*U*V*C4/BL) - 1.0
LIMIT CHECKS
QR ≥ QRMAX
YES
QR = QRMAX
QR ≤ QRMIN
YES
PR = QRMIN
NO
|QRAS - QR| > QTOL
EXIT
OPERATOR MESSAGE
LIGHT OPERATOR LIGHT
EXIT

RESPIROMETER CONTROL FLOWCHART

# APPENDIX B

# DETAILS OF F/M RATIO CONTROLLERS ALGORITHM DESIGN

# APPENDIX B

## Details of F/M Ratio Controllers Algorithm Design

### B.1 STEADY STATE RAS FLOW TO MAINTAIN TO GIVEN MLSS CONCENTRATION.

A microorganism mass balance around the aerators (Schematic in Figure B.1) yields

$$V_a \frac{dX_a}{dt} = Q_R X_R - \left(Q + Q_R + Q_W\right)X_a + \overbrace{Y\frac{dF}{dt} - K_d X_a V_a}^{\text{net microorganism growth in aerators}} \qquad (B.1)$$

In steady state

$$\frac{dX_a}{dt} = 0 \qquad (B.2)$$

and for no sludge build-up or depletion in the total secondary system

$$Q_W X_a = Y\frac{dF}{dt} - K_d\left(X_a V_a + X_c V_c\right) \qquad (B.3)$$

The right hand side of Equation B.3 is net cell growth in the total secondary plant volume. Using Equations B.3 and B.2 with B.1 yields

$$0 = Q_R\left(X_R - X_a\right) - QX_a + K_d X_c V_c \qquad (B.4)$$

and therefore

$$Q_R = \frac{Q\left[1 - \left[\dfrac{K_d X_c V_c}{QX_a}\right]\right]}{\dfrac{X_R}{X_a} - 1} \qquad (B.5)$$

The quantity $K_d X_c V_c/(QX_a)$ is much less than 1.0 (about .01 for Palo Alto) and can therefore be neglected; so that

$$Q_R = \frac{Q}{\dfrac{X_R}{X_a} - 1} \qquad (B.6)$$

### B.2 RELATIONSHIP BETWEEN FOOD UPTAKE AND AIR CONSUMPTION IN SECONDARY TREATMENT.

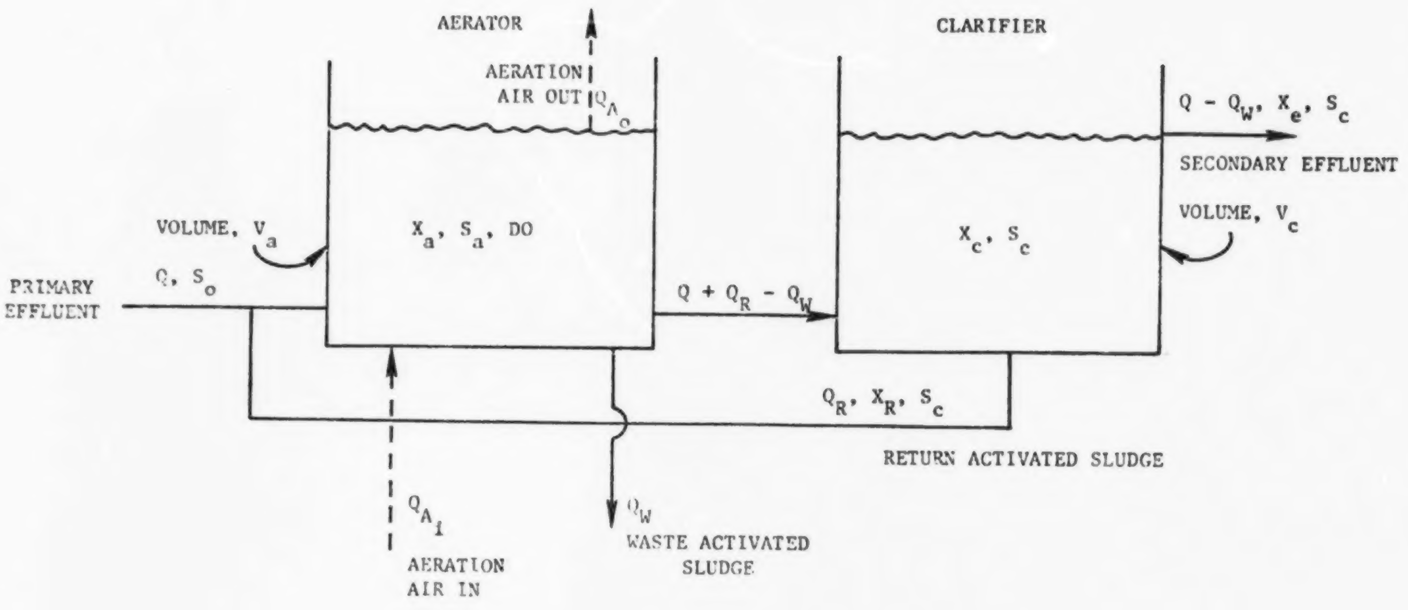

AERATOR
AERATION AIR OUT $Q_{A_o}$
CLARIFIER
VOLUME, $V_a$
$X_a$, $S_a$, DO
PRIMARY EFFLUENT
Q, $S_o$
$Q + Q_R - Q_W$
$X_c$, $S_c$
$Q - Q_W$, $X_e$, $S_c$
SECONDARY EFFLUENT
VOLUME, $V_c$
$Q_R$, $X_R$, $S_c$
RETURN ACTIVATED SLUDGE
$Q_{A_i}$
AERATION AIR IN
$Q_W$
WASTE ACTIVATED SLUDGE

FIGURE B.1. ACTIVATED SLUDGE PROCESS SCHEMATIC

An oxygen mass balance for biological respiration in the aerators yields

$$Q_{O_2} = [1 - YyL] \frac{dF}{dt} + yLK_d\overline{X} \left(V_a + V_c\right) \qquad (B.7)$$

where L is the fraction of original $BOD_5$ demand remaining in the bio mass after cell synthesis, y is the $BOD_5$ mass demand per unit mass of microorganism cells, and Y is mass yield of microorganisms per unit mass of food consumed. A microorganism mass balance around the entire secondary system is

$$\left(V_a + V_c\right) \frac{d\overline{X}}{dt} = Y\frac{dF}{dt} - K_d\overline{X} \left(V_a + V_c\right) - \left(Q_W X_a + QX_e\right) \qquad (B.8)$$

where $\overline{X}$ is the average microorganism density, in the entire secondary system. Since the wasting rate policy is

$$Q_W = \frac{\left(V_a + V_c\right)}{\theta_c} - \frac{QX_c}{X_a} \qquad (B.9)$$

Equation B.8 can be rewritten

$$\frac{d\overline{X}}{dt} = \frac{Y}{V_a + V_c} \frac{dF}{dt} - K_d\overline{X} - \frac{X_a}{\theta_c} \qquad (B.10)$$

On average, whatever control policy is followed, $\overline{X} \approx X_a$, so Equation B.10 becomes

$$\frac{d\overline{X}}{dt} = - \left(K_d + \frac{1}{\theta_c}\right)\overline{X} + \left(\frac{Y}{V_a + V_c}\right) \frac{dF}{df} \qquad (B.11)$$

Then, substituting for $K_d\overline{X}$ from Equation B.11 into Equation B.7 yields

$$Q_{O_2} = \frac{dF}{dt} - \left(V_a + V_c\right) yL \left[\frac{X}{\theta_c} + \frac{d\overline{X}}{dt}\right] \qquad (B.12)$$

For a diurnal variation in dF/(dt) with a constant part, $d\overline{F}/(dt)$, and a dominant varying component that is sinusoidal, 1/2 $d\overline{F}/(dt)$ sin ωt, driving Equation B.11, then in the steady state

$$\frac{\overline{X}}{\theta_c} + \frac{d\overline{X}}{dt} = \frac{Y}{\left(V_a + V_C\right)} \frac{dF}{dt} [1-b + \frac{1}{2} [[ \left(1- \frac{b}{a}\right)^2 - \left(\frac{b\tau\omega}{a}\right)^2]^{\frac{1}{2}} . \qquad (B.13)$$

$$\cdot \sin\left[\omega t + \tan^{-1}\left(\frac{b\tau\omega}{a - b}\right)\right]\Bigg]\Bigg]$$

where

$$a = \left(\tau^2\omega^2 + 1\right)^{\frac{1}{2}} \qquad \text{(a)}$$

$$b = \tau K_d \qquad \text{(b)} \qquad \text{(B.14)}$$

$$\tau = \frac{\theta_c}{K_d\theta_c + 1} \qquad \text{(c)}$$

For typical operating conditions:

$$\theta_c = 10 \text{ days}, \; K_d = 0.05 \text{ days}^{-1}, \; \omega = \frac{1}{2\pi} \text{ days}^{-1}$$

the ratio of the constant part of Equation B.13 to the amplitude of the sinusoidal part is about 2 to 1. Therefore, a simplification of Equation B.13 can be made such that

$$\frac{\overline{X}}{\theta_c} + \frac{d\overline{X}}{dt} \approx \frac{Y}{V_a + V_c}\frac{dF}{dt} \qquad \text{(B.15)}$$

and substitution of Equation B.15 into B.12 to give:

$$Q_{O_2} = \left[1 - YyL\left(\frac{1}{K_d\theta_c + 1}\right)\right]\frac{dF}{dt} \qquad \text{(B.16)}$$

If a mass balance for air in the aerators is developed:

$$\frac{d\,DO}{dt} = Q_{A_i} - Q_{A_o} - Q_{O_2} \qquad \text{(B.17)}$$

and an assumption made about the relationship between $Q_{A_i}$ and $Q_{A_o}$

$$Q_{A_i} - Q_{A_o} = K_1\,Q_{A_2} + K_2 \qquad \text{(B.18)}$$

then for a constant DO level (i.e. d DO/(dt) = 0)

$$\frac{dF}{dt} = \frac{1}{1 - \dfrac{YyL}{K_d\theta_c + 1}}\left[K_1\,Q_{A_i} + K_2\right] \qquad \text{(B.19)}$$

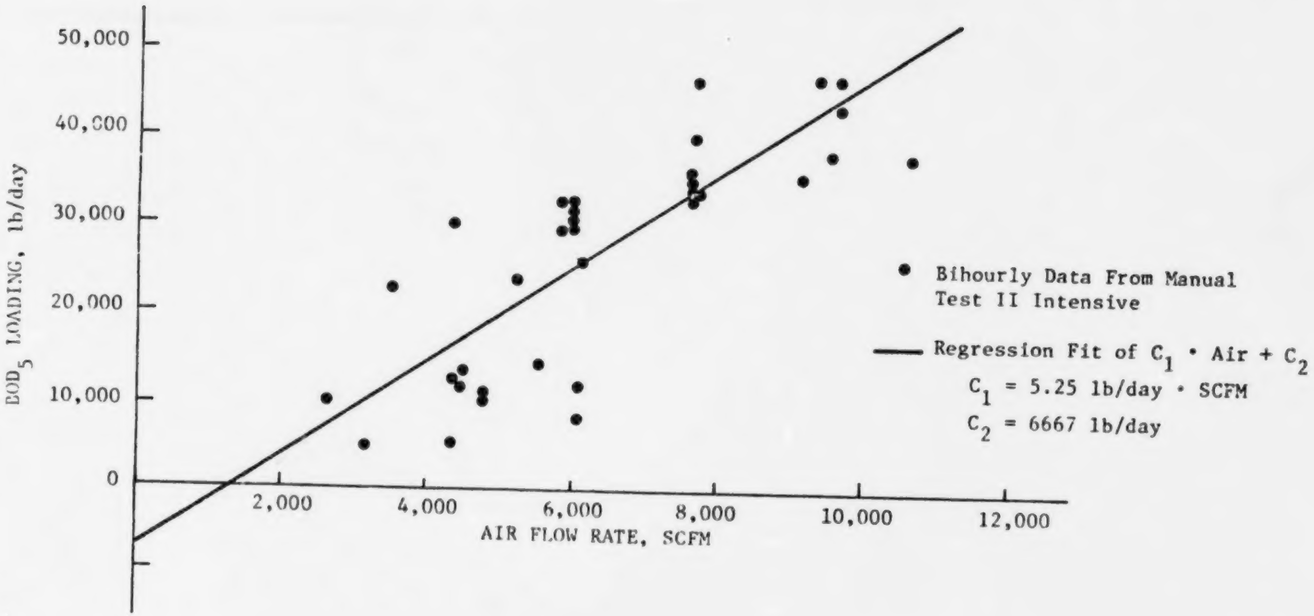


FIGURE B.2. REGRESSION CORRELATION OF SECONDARY TREATMENT $BOD_5$ LOADING AND AERATION AIR FLOW

The constants $K_1$ and $K_2$ relate the amount of air required to put a given quantity of oxygen into solution. Since the relationship is a complex function of temperatures, flow rates, bubble size, and agitation; Equation B.19 is put into the form

$$\frac{dF}{dt} = c_1 \, Q_{A_i} + C_2 \qquad \text{(B.20)}$$

and $c_1$, $c_2$ are determined empirically by regression (see Figure B.2) with plant operating data. For Palo Alto in the conventional mode operation in the wet season

$$c_1 = 0.63 \, \frac{\text{mg·MGD}}{\text{l·SCFM}}$$

$$c_2 = -800 \, \frac{\text{mg·MGD}}{\text{l·}}$$

## B.3 RELATIONSHIP BETWEEN FOOD UPTAKE AND SUBSTRATE LOAD IN SECONDARY TREATMENT

In section B.2, the relationship between food uptake, dF/(dt), and air use is developed. Substrate loading changes, $QS_o$, will not, in general, result in instantaneous uptake rates. The lag in uptake can be determined using a substrate mass balance for the aerators:

$$V_a \frac{dS_a}{dt} = QS_o - V_a \frac{dF}{dt} - (Q + Q_R) \; S_a + Q_R S_c \qquad \text{(B.21)}$$

In general, $S_a$, substrate concentration in the aerators, is approximately the same as $S_c$, substrate concentration in the clarifier. From Reference [7], the relation between food uptake, dF/(dt), and substrate concentration is

$$\frac{dF}{dt} = \frac{KX_a S_a}{K_s + S_a} \qquad \text{(B.22)}$$

so that Equation B.21 becomes

$$\frac{dS_a}{dt} = -\left[\frac{KX_a}{K_s + S_a} + \frac{Q}{V_a}\right] S_a + QS_o \qquad \text{(B.23)}$$

$S_a$ for proper operation is always much less than $K_s$ so that the time constant, $\tau_{S_a}$, for $S_a$ changes in the aerator is

$$\tau_{S_a} = \frac{1}{\dfrac{KX_a}{K_s + S_a} + \dfrac{Q}{V_a}} \qquad \text{(B.24)}$$

For Palo Alto, realistic values for parameters of Equation B.24 are: $K = 10\ \text{days}^{-1}$, $K_s = 100$ mg/l, $X_a = 1200$ mg/l, $S_a \approx 10$ mg/l, $Q = 30$ MGD ($0.11\ \text{Mm}^3$/day) and $V_a = 7.2$ MG ($0.027\ \text{Mm}^3$). Therefore, $\tau_{S_a} \approx 10$ minutes which means that the time lag between substrate load and uptake is short enough to be neglected.

Thus, $dS_a/(dt)$ can be assumed zero in Equation B.21 yielding

$$Q(S_o = S_a) = \frac{1}{V_a}\frac{dF}{dt} \qquad \text{(B.25)}$$

and since $S_a$ is a constant fraction, f, of $S_o$ for a given removal efficiency

$$Q\ S_o(1 - f) = \frac{1}{V_a}\frac{dF}{dt} \qquad \text{(B.26)}$$

Loading, $QS_o$, is thus directly proportional to food uptake, $dF/(dt)$; which, in turn, as shown in section B.2, is a function of air use in the aerators.

## B.4 AVERAGE FOOD UPTAKE TO MICROORGANISM RATIO AS A FUNCTION OF MEAN CELL RESIDENCE TIME

Average F/M ratio, U, is defined

$$U = \frac{\frac{dF}{dt}}{V_a\ \bar{X}_a\ f_v} \qquad \text{(B.27)}$$

Using the long term average of Equation B.11 (i.e. $d\bar{X}/(dt) = 0$) and the fact that $X_a \approx X$ then

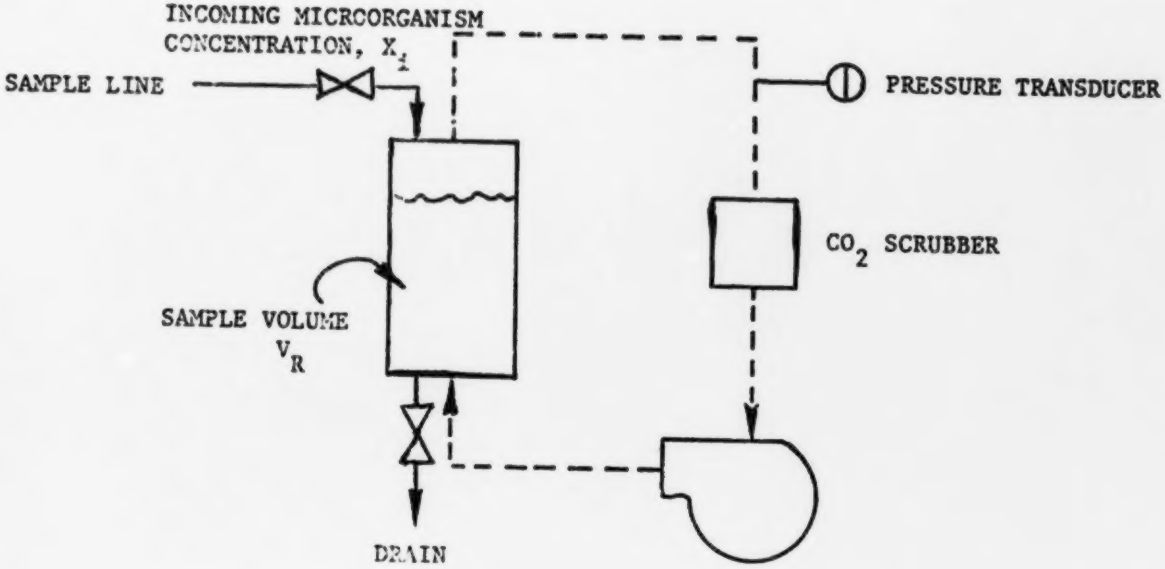
$$U = \frac{\left(K_d + \frac{1}{\theta_c}\right)\left(V_a + V_c\right)}{Y\quad V_a\ f_v} \qquad \text{(B.28)}$$

## B.5 RELATIONSHIP OF RESPIROMETER MEASUREMENT TO FEED UPTAKE

A mass balance on oxygen in the closed sampling system of the respirometer shown schematically in Figure B.3 is:

$$R = (1 - YyL)\left(\frac{1}{V_R}\frac{dF}{dt} + K_d X_i\right) + LyK_d X_n \qquad \text{(B.29)}$$

when $X_i$ is the initial microorganism mass concentration and $X_n$ is the concentration of new microorganism synthesis once the sampling period begins. Respiration rate, R, is measured in the instrument by the pressure drop as oxygen is consumed in respiration and any carbon dioxide produced is removed by the soda lime scrubber.


INCOMING MICROORGANISM CONCENTRATION, $X_i$
SAMPLE LINE
PRESSURE TRANSDUCER
$CO_2$ SCRUBBER
SAMPLE VOLUME $V_R$
DRAIN

Sample System Loaded and Operated
for Sample Time, T.

FIGURE B.3. RESPIROMETER SCHEMATIC

Microorganism mass balances are

$$\frac{dX_i}{dt} = - K_d X_i \tag{B.30}$$

for the original cells and

$$\frac{dX_n}{dt} = Y\left(\frac{dF}{dt} + K_d X_i\right) - K_d X_n \tag{B.31}$$

for the new calls. If dF/(dt) is assumed constant for the sampling period, solutions to Equations B.30 and B.31 are

$$X_i = X_{i_o} e^{-K_d t} \tag{B.32}$$

and

$$X_n = \frac{Y}{K_d V_R} \frac{dF}{dt} \left(1 - e^{-K_d t}\right) + Y K_d X_{i_o} t e^{-K_d t} \tag{B.33}$$

Substituting Equation B.32 and B.33 into B.29 and integrating for the sample period T yields:

$$\int_o^T = RT = \frac{dF}{dt}\left[T - \left(1 - e^{-K_d T}\right) \frac{LyY}{K_d}\right] + V_R X_{i_o} \left[\left(1 - e^{-K_d T}\right) - LyYK_d T e^{-K_d T}\right] \tag{B.34}$$

With the simplification, 1 - x, for the exponential $e^{-x}$ with x small $\left(K_d T = \left(\frac{.05}{24} \text{ hr}^{-1}\right)\left(\frac{3}{4} \text{ hr}\right) = 0.00156\right)$

$$R = \frac{dF}{dt}\left[1 - LyY\right] + K_d V_R X_{i_o} \left[1 - LyYK_d T\right] \tag{B.35}$$

or since $LyYK_d T << 1$

$$\frac{dF}{dt} = \frac{R - K_d V_R X_{i_o}}{1 - LyY} \tag{B.36}$$

## APPENDIX C

## SUMMARY OF COMPUTER OUTPUT*

---

*Adjusted for uniform plant conditions.

# APPENDIX C.1

# MANUAL-I DATA

```
JULY  9 1973  TO  AUG   7 1973          PROCESS DATA SUMMARY                    MANUAL PLANT CONTROL

        DESCRIPTION                     AVE          MIN            MAX              STD        UNITS

   TOTAL PLANT FLOW                   24.06          5.59          36.48             4.53       MGD
   LOS ALTOS FLOW                     SENSOR NOT OPERABLE
   MT. VIEWFLOW                       SENSOR NOT OPERABLE
   P H                                 7.92          6.69           8.24             0.27
   D O #1                              0.04          0.0            0.15             0.07       MG/LITER
   D O #2                              0.13          0.0            1.27             0.15       MG/LITER
   D O #3                              0.99          0.57           3.66             0.35       MG/LITER
   D O #4                              1.58          0.00           5.07             1.31       MG/LITER
   AIRFLOW #1                       2000.56        960.13        3064.88           260.73       CFM
   AIRFLOW #2                        954.30         21.62        1684.69           199.47       CFM
   AIRFLOW #3                       2003.95        917.25        2940.63           252.70       CFM
   AIRFLOW #4                       2094.80       1053.31        2893.50           288.13       CFM
   TH #1 FLOW                         25.10          0.0           60.84            20.54       GPM
   TH #1 DENSITY                       5.01          0.40           5.19             0.16       PERCENT
   TH #2 FLOW                         13.24          0.0           61.06            17.89       GPM
   TH #2 DENSITY                       4.82          4.82           4.82             0.04       PERCENT
   TH #3 FLOW                          5.32          0.0           57.69            12.45       GPM
   TH #3 DENSITY                       2.82          0.0            6.16             2.40       PERCENT
   TH #4 FLOW                         23.69          0.0           61.05            20.37       GPM
   TH #4 DENSITY                       4.85          4.85           4.86             0.04       PERCENT
   RAS FLOW                            8.88          6.96          25.34             3.29       MGD
   WAS FLOW                            2.43          0.52           3.12             0.27       MGD
   MLSS                             1699.72        321.41        2692.38           386.00       MG/LITER
   SLUDGE BLANKET                      0.0           0.0            0.0              0.0        FT
   CHLORINE #1 RESIDUAL                0.0           0.0            0.0              0.0        MG/LITER
   CHLORINE FLOW #1                    0.0           0.0            0.0              0.0        LB/DAY
   CHLORINE FLOW #2                    0.0           0.0            0.0              0.0        LB/DAY
   CHLORINE FLOW #3                    0.0           0.0            0.0              0.0        LB/DAY
   CHLORINE #2 RESIDUAL                0.0           0.0            0.0              0.0        MG/LITER
   SULFUR DIOXIDE FLOW                 0.0           0.0            0.0              0.0        LB/DAY
   SPARE                               0.0           0.0            0.0              0.0
   SPARE                              NO VALID DATA
```

JULY 9 1973 TO AUG 7 1973 LOADING DATA SUMMARY MANUAL PLANT CONTROL

|  | SS(LBS) |  | BOD(LBS) |  | TOC(LBS) |  | COD(LBS) |  |
|---|---|---|---|---|---|---|---|---|
|  | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT |
| JULY 9 1973 | 74.8 % | 5475. | 100.0 % | 0. | 55.9 % | 8800. | 67.5 % | 19555. |
| JULY 10 1973 | 73.6 % | 7755. | 86.7 % | 4408. | 64.4 % | 6531. | 68.6 % | 16940. |
| JULY 11 1973 | 85.3 % | 5775. | 87.6 % | 4208. | 66.1 % | 7838. | 71.6 % | 18976. |
| JULY 12 1973 | 84.6 % | 5441. | 88.3 % | 4111. | 76.2 % | 7254. | 75.0 % | 16322. |
| JULY 13 1973 | 81.9 % | 6611. | 94.6 % | 1683. | 66.8 % | 6010. | 73.1 % | 15625. |
| JULY 14 1973 | 75.4 % | 5821. | 82.9 % | 3929. | 64.0 % | 5821. | 70.2 % | 13643. |
| JULY 15 1973 | 81.2 % | 3832. | 83.8 % | 3553. | 64.9 % | 5922. | 75.9 % | 9927. |
| JULY 16 1973 | 90.9 % | 3640. | 91.9 % | 2548. | 63.9 % | 7886. | 79.1 % | 12941. |
| JULY 17 1973 | 86.9 % | 3920. | 90.6 % | 3837. | 61.0 % | 9490. | 80.0 % | 14854. |
| JULY 18 1973 | 83.7 % | 5607. | 91.2 % | 3536. | 67.9 % | 8194. | 83.3 % | 14721. |
| JULY 19 1973 | 75.8 % | 5964. | 86.3 % | 5676. | 52.2 % | 8844. | 85.8 % | 20772. |
| JULY 20 1973 | 70.5 % | 8711. | 87.2 % | 4717. | 67.0 % | 7649. | 73.0 % | 19122. |
| JULY 21 1973 | 68.6 % | 8469. | 81.6 % | 5428. | 59.6 % | 7314. | 68.5 % | 17901. |
| JULY 22 1973 | 60.3 % | 8771. | 85.0 % | 3782. | 52.5 % | 8588. | 66.4 % | 15350. |
| JULY 23 1973 | 77.9 % | 7187. | 91.4 % | 3044. | 63.8 % | 8879. | 76.3 % | 14798. |
| JULY 24 1973 | 78.3 % | 7446. | 85.1 % | 3971. | 72.3 % | 8894. | 75.7 % | 17375. |
| JULY 25 1973 | 72.7 % | 8392. | 83.7 % | 4196. | 57.8 % | 9790. | 74.9 % | 17782. |
| JULY 26 1973 | 78.9 % | 6235. | 83.3 % | 4345. | 63.1 % | 9655. | 73.6 % | 17901. |
| JULY 27 1973 | 81.1 % | 7415. | 89.2 % | 3305. | 69.6 % | 8051. | 80.0 % | 21822. |
| JULY 28 1973 | 80.6 % | 6373. | 88.3 % | 2781. | 68.8 % | 6566. | 72.0 % | 17767. |
| JULY 29 1973 | 87.8 % | 4119. | 90.0 % | 2042. | 73.4 % | 4478. | 71.4 % | 13791. |
| JULY 30 1973 | 80.6 % | 6427. | 81.9 % | 3374. | 72.0 % | 7030. | 77.4 % | 15064. |
| JULY 31 1973 | 76.2 % | 7736. | 85.6 % | 4764. | 68.8 % | 7125. | 79.3 % | 16287. |
| AUG 1 1973 | 73.8 % | 11381. | 86.9 % | 5214. | 83.8 % | 8277. | 74.2 % | 19037. |
| AUG 2 1973 | 70.4 % | 9466. | 89.3 % | 3786. | 62.6 % | 8414. | 69.4 % | 20193. |
| AUG 3 1973 | 80.6 % | 10573. | 87.9 % | 4354. | 59.0 % | 9951. | 73.8 % | 18659. |
| AUG 4 1973 | 73.0 % | 9290. | 88.8 % | 3470. | 67.2 % | 7537. | 83.5 % | 16651. |
| AUG 5 1973 | 84.2 % | 7378. | 89.6 % | 3889. | 72.1 % | 7673. | 79.0 % | 16634. |
| AUG 6 1973 | 83.4 % | 7161. | 88.3 % | 4982. | 73.0 % | 7854. | 79.8 % | 16880. |
| AUG 7 1973 | 74.5 % | 9965. | 87.1 % | 4990. | 71.5 % | 8878. | 75.5 % | 20058. |

```
JULY  9 1973  TO  AUG   7 1973         LOADING DATA SUMMARY             MANUAL PLANT CONTROL

                         NH3(LBS)            NO2(LBS)            NO3(LBS)            PHOS(LBS)

                   %REMOVED|EFFLUENT   %REMOVED|EFFLUENT   %REMOVED|EFFLUENFT  %REMOVED|EFFLUENT

JULY  9 1973          15.4 %     4850.     86.7 %        6.     95.7 %       12.      0.0 %     1056.
JULY 10 1973          20.8 %     7755.     97.6 %        2.     99.7 %        2.    -50.9 %     1694.
JULY 11 1973         -74.1 %     9157.     96.7 %        2.     99.7 %        2.    -94.4 %     1444.
JULY 12 1973          18.2 %     5803.     97.9 %        2.     99.6 %        2.      9.5 %      766.
JULY 13 1973          13.2 %     5288.     96.9 %        2.     99.5 %        2.      7.0 %     1062.
JULY 14 1973           0.0 %     4948.     85.3 %        2.     96.8 %        2.    -27.8 %     1255.
JULY 15 1973         -23.9 %     3971.      0.0 %        2.      0.0 %        2.     33.3 %      592.
JULY 16 1973          41.1 %     4529.     96.9 %        2.     99.5 %        2.      0.0 %     1092.
JULY 17 1973           2.6 %     6106.     97.8 %        2.     99.6 %        2.    -48.1 %     1589.
JULY 18 1973          10.8 %     6437.     96.6 %        2.     99.5 %        2.    -28.1 %     1377.
JULY 19 1973           5.0 %     6252.     97.8 %        2.     99.6 %        2.    -40.7 %     1563.
JULY 20 1973          16.7 %     6374.     87.8 %        2.     98.5 %        2.    -30.9 %     1530.
JULY 21 1973           6.7 %     5389.      0.0 %        2.      0.0 %        2.     -8.6 %     1213.
JULY 22 1973         -23.6 %     4970.     88.1 %        2.     97.1 %        2.    -56.0 %      713.
JULY 23 1973          16.7 %     5073.     91.5 %        2.     98.6 %        2.      9.1 %     1057.
JULY 24 1973          12.5 %     7239.     92.9 %        2.     99.0 %        2.    -26.7 %     1375.
JULY 25 1973          13.3 %     7193.     97.0 %        2.     99.3 %        2.     17.1 %     1409.
JULY 26 1973           3.0 %     7804.     97.4 %        2.     99.5 %        2.    -39.9 %     1452.
JULY 27 1973          -5.2 %     7246.     91.7 %        2.     98.5 %        2.    -14.7 %     1409.
JULY 28 1973           4.5 %     6180.     83.3 %        2.     96.6 %        2.      6.3 %     1031.
JULY 29 1973         -10.0 %     4925.      0.0 %        2.      0.0 %        2.     25.5 %      707.
JULY 30 1973          21.6 %     5825.     96.9 %        2.     99.5 %        2.      6.6 %      940.
JULY 31 1973          16.9 %     4988.     99.8 %        0.    100.0 %        0.    -32.2 %     1303.
AUG   1 1973          20.4 %     4614.     97.3 %        2.     99.5 %        2.    -23.3 %     1316.
AUG   2 1973          14.8 %     5469.     97.3 %        2.     99.1 %        2.    -14.5 %     1199.
AUG   3 1973          -5.0 %     8707.     94.8 %        2.     98.8 %        2.     -8.7 %     1275.
AUG   4 1973         -27.7 %     7274.     58.3 %        2.     92.9 %        2.    -23.7 %     1060.
AUG   5 1973          -6.6 %     4568.     82.7 %        2.     96.1 %        2.      2.7 %      885.
AUG   6 1973          24.0 %     4620.     95.8 %        2.     99.3 %        2.      6.1 %     1263.
AUG   7 1973           5.6 %     6954.     96.3 %        2.     99.4 %        2.    -41.2 %     1886.
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JULY  9 1973  TO  AUG   7 1973          PLANT AIR CONSUMPTION              MANUAL PLANT CONTROL
     AIRFLOWS IN CUBIC FEET            ASSUMED COST -  $.000095/CF


                           AIRFLOW#1     AIRFLOW#2     AIRFLOW#3     AIRFLOW#4          TOTAL          COST

JULY  9 1973                2652753.      1339943.      2804291.      3232977.      10029964.    $   952.85
JULY 10 1973                2706295.      1395984.      2869241.      3285297.      10256817.    $   974.40
JULY 11 1973                2413933.      1102778.      2521453.      2998325.       9036489.    $   858.47
JULY 12 1973                2727619.      1380698.      2863347.      3255660.      10227324.    $   971.60
JULY 13 1973                2724681.      1378603.      2865183.      3254859.      10223326.    $   971.22
JULY 14 1973                2750203.      1394967.      2850313.      3192407.      10187890.    $   967.85
JULY 15 1973                2727329.      1451949.      2795265.      3096833.      10071376.    $   956.78
JULY 16 1973                2763581.      1160880.      2807237.      3276585.      10008283.    $   950.79
JULY 17 1973                2930311.      1544034.      2987671.      2776055.      10238071.    $   972.62
JULY 18 1973                2806647.      1573373.      2831971.      2969141.      10181332.    $   967.23
JULY 19 1973                2776771.      1677903.      2641155.      3169867.      10265696.    $   975.24
JULY 20 1973                2829813.      1338812.      2700923.      3321679.      10191227.    $   968.17
JULY 21 1973                2838729.      1430872.      2723517.      2939643.       9932761.    $   943.61
JULY 22 1973                2945117.      1607674.      2846639.      2832617.      10232047.    $   972.04
JULY 23 1973                2942641.      1493985.      2811275.      2928497.      10176398.    $   966.76
JULY 24 1973                2997731.      1513004.      2851547.      2963329.      10325611.    $   980.93
JULY 25 1973                2942043.      1442067.      2777893.      2936967.      10098970.    $   959.40
JULY 26 1973                2954511.      1411051.      2762645.      2945785.      10073992.    $   957.03
JULY 27 1973                3033717.      1514040.      2855447.      2991393.      10394597.    $   987.49
JULY 28 1973                2986915.      1579331.      2843795.      2844743.      10256784.    $   974.39
JULY 29 1973                2846761.      1568572.      2851751.      2885747.      10152831.    $   964.52
JULY 30 1973                2865529.      1457704.      3033419.      2905177.      10261829.    $   974.87
JULY 31 1973                3013675.      1173467.      3105067.      2840401.      10132610.    $   962.60
AUG   1 1973                3030785.      1245846.      3105115.      2811421.      10193167.    $   968.35
AUG   2 1973                3033989.      1229986.      3077407.      2848349.      10189731.    $   968.02
AUG   3 1973                3011375.      1133828.      3047875.      2938947.      10132025.    $   962.54
AUG   4 1973                2994489.      1155212.      3038314.      2877211.      10065226.    $   956.20
AUG   5 1973                3276707.      1291274.      3349701.      3187881.      11105563.    $  1055.03
AUG   6 1973                3052575.      1099029.      3112945.      3031857.      10296406.    $   978.16
AUG   7 1973                3035107.      1078834.      3063431.      3018227.      10195599.    $   968.58

  TOTAL                    86614336.     41165568.     86795648.     90557712.     305133312.    $ 28987.66
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JULY  9 1973  TO  AUG   7 1973          MONTHLY EFFICIENCY SUMMARY          MANUAL PLANT CONTROL


                              PRIMARY                    SECONDARY                    CHLORINATOR
                        AVE         STD        AVE          STD          AVE         STD
    SS                  51.4 %       11.6 %       73.9 %         8.9 %       78.2 %         6.5 %
    BOD5                22.9 %       12.0 %       87.6 %         2.9 %       87.4 %         3.3 %
    TOC                 26.1 %       13.1 %       65.3 %         6.3 %       66.1 %         7.0 %
    COD                 33.6 %       10.9 %       75.[illegible] %         4.4 %       75.1 %         4.9 %


JULY  9 1973  TO  AUG   7 1973          RESPIRATION SUMMARY               MANUAL PLANT CONTROL


   UNITS - LBS LOADING / 1000 CUBIC FEET OF AERATOR TANKAGE

                        SS            BOD            TOC            COD

   AVE                 21.88         34.05          23.92          62.92

   STD                  4.72          8.08           4.20           9.48
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# APPENDIX C.2

# DO DATA

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AUG  12 1973  TO  SEPT 11 1973         PROCESS DATA SUMMARY              AUTOMATIC PLANT CONTROL
        DESCRIPTION               AVE          MIN          MAX          STD       UNITS
   TOTAL PLANT FLOW              23.57        13.05        37.65         4.59      MGD
   LOS ALTOS FLOW                SENSOR NOT OPERABLE
   MT. VIEWFLOW                  SENSOR NOT OPERABLE
   P H                            7.28         6.61         8.11         0.15
   D O #1                         0.99         0.01         4.84         0.54      MG/LITER
   D O #2                         1.01         0.10         5.09         0.56      MG/LITER
   D O #3                         0.34         0.0          3.04         0.34      MG/LITER
   D O #4                         1.13         0.05         5.01         0.59      MG/LITER
   AIRFLOW #1                  2208.38       315.20      3603.63       517.16      CFM
   AIRFLOW #2                  1125.60         4.29      3025.75       511.94      CFM
   AIRFLOW #3                  2280.35       181.37      3668.88       534.67      CFM
   AIRFLOW #4                  1569.53       402.25      3102.25       446.15      CFM
   TH #1 FLOW                     1.12         0.0         60.36         2.38      GPM
   TH #1 DENSITY                  5.45         0.43         5.64         0.19      PERCENT
   TH #2 FLOW                    25.75         0.0         61.06        12.06      GPM
   TH #2 DENSITY                  5.41         0.0          7.35         0.58      PERCENT
   TH #3 FLOW                    29.98         0.0         60.73        12.88      GPM
   TH #3 DENSITY                  2.76         0.0          8.94         2.09      PERCENT
   TH #4 FLOW                     0.97         0.0         60.71         7.50      GPM
   TH #4 DENSITY                  5.71         0.0          5.92         0.74      PERCENT
   RAS FLOW                       8.67         1.60        18.57         1.19      MGD
   WAS FLOW                       1.72         0.41         2.83         0.26      MGD
   MLSS                        1273.17       896.00      2020.06       196.10      MG/LITER
   SLUDGE BLANKET               425.67         3.70      2214.25       559.73      FT
   CHLORINE #1 RESIDUAL           0.0          0.0          0.0          0.0       MG/LITER
   CHLORINE FLOW #1               0.0          0.0          0.0          0.0       LB/DAY
   CHLORINE FLOW #2               0.0          0.0          0.0          0.0       LB/DAY
   CHLORINE FLOW #3               0.0          0.0          0.0          0.0       LB/DAY
   CHLORINE #2 RESIDUAL           0.0          0.0          0.0          0.0       MG/LITER
   SULFUR DIOXIDE FLOW            0.39         0.0         13.54         1.52      LB/DAY
   SPARE                          0.0          0.0          0.0          0.0
   SPARE                         NO VALID DATA
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AUG 12 1973 TO SEPT 11 1973 LOADING DATA SUMMARY AUTOMATIC PLANT CONTROL

| | SS(LBS) | | BOD(LBS) | | TOC(LBS) | | COD(LBS) | |
|---|---|---|---|---|---|---|---|---|
| | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT |
| AUG 12 1973 | 78.6 % | 6612. | 87.6 % | 2534. | 61.9 % | 6795. | 72.9 % | 17080. |
| AUG 13 1973 | 79.0 % | 5440. | 76.8 % | 4519. | 67.3 % | 6695. | 76.9 % | 17994. |
| AUG 14 1973 | 79.7 % | 5921. | 84.5 % | 4313. | 66.7 % | 6766. | 74.4 % | 19665. |
| AUG 15 1973 | 73.1 % | 7560. | 85.2 % | 3260. | 73.3 % | 5434. | 71.6 % | 17955. |
| AUG 16 1973 | 70.5 % | 6599. | 75.6 % | 11240. | 56.8 % | 6812. | 77.6 % | 16391. |
| AUG 17 1973 | 82.5 % | 4409. | 90.5 % | 4199. | 65.6 % | 6718. | 78.1 % | 14695. |
| AUG 18 1973 | 84.2 % | 4339. | 81.7 % | 7358. | 73.7 % | 4905. | 78.9 % | 13206. |
| AUG 19 1973 | 84.5 % | 3909. | 81.5 % | 2985. | 65.9 % | 4975. | 74.8 % | 11905. |
| AUG 20 1973 | 77.5 % | 5865. | 87.0 % | 2912. | 75.3 % | 4652. | 76.6 % | 13753. |
| AUG 21 1973 | 81.5 % | 5030. | 92.6 % | 3353. | 68.4 % | 6287. | 76.2 % | 15718. |
| AUG 22 1973 | 73.1 % | 7522. | 88.2 % | 6519. | 67.0 % | 6477. | 75.2 % | 15880. |
| AUG 23 1973 | 60.9 % | 8782. | 86.6 % | 4779. | 62.8 % | 7148. | 66.2 % | 19197. |
| AUG 24 1973 | 68.4 % | 7454. | 86.0 % | 6527. | 56.5 % | 8059. | 67.3 % | 18334. |
| AUG 25 1973 | 77.6 % | 5992. | 87.8 % | 5505. | 68.9 % | 6179. | 65.1 % | 21720. |
| AUG 26 1973 | 72.1 % | 5469. | 79.2 % | 8680. | 63.6 % | 5646. | 72.1 % | 12879. |
| AUG 27 1973 | 96.1 % | 1238. | 78.7 % | 10525. | 70.0 % | 8048. | 89.7 % | 7636. |
| AUG 28 1973 | 83.2 % | 3538. | 87.2 % | 6132. | 58.3 % | 7862. | 73.2 % | 15527. |
| AUG 29 1973 | 63.9 % | 8601. | 90.1 % | 4920. | 64.8 % | 7601. | 71.4 % | 17802. |
| AUG 30 1973 | 63.9 % | 9359. | 84.3 % | 5737. | 61.8 % | 7935. | 71.2 % | 20956. |
| AUG 31 1973 | 80.9 % | 5866. | 90.4 % | 3034. | 68.4 % | 7484. | 72.2 % | 18408. |
| SEPT 1 1973 | 66.2 % | 8385. | 82.3 % | 5974. | 44.9 % | 7512. | 68.9 % | 18867. |
| SEPT 2 1973 | 74.6 % | 4931. | 75.8 % | 7039. | 60.8 % | 5271. | 76.2 % | 13092. |
| SEPT 3 1973 | 82.0 % | 4962. | 78.9 % | 8110. | 73.2 % | 4449. | 78.5 % | 13175. |
| SEPT 4 1973 | 87.4 % | 3568. | 79.5 % | 9038. | 73.2 % | 5946. | 78.2 % | 15460. |
| SEPT 5 1973 | 81.5 % | 6224. | 86.0 % | 6721. | 76.9 % | 5809. | 75.4 % | 16389. |
| SEPT 6 1973 | 79.1 % | 5864. | 83.5 % | 7400. | 74.8 % | 5864. | 71.6 % | 16782. |
| SEPT 7 1973 | 78.2 % | 4471. | 68.0 % | 8780. | 56.2 % | 7927. | 64.8 % | 21341. |
| SEPT 8 1973 | 83.1 % | 4140. | 88.0 % | 2794. | 70.9 % | 3967. | 75.4 % | 11385. |
| SEPT 9 1973 | 87.8 % | 3163. | 89.1 % | 2704. | 70.9 % | 5515. | 81.6 % | 9938. |
| SEPT 10 1973 | 86.3 % | 4572. | 91.4 % | 2547. | 76.1 % | 5792. | 81.0 % | 13286. |
| SEPT 11 1973 | 83.5 % | 5118. | 88.1 % | 3771. | 72.9 % | 6371. | 78.2 % | 15563. |

AUG 12 1973 TO SEPT 11 1973 LOADING DATA SUMMARY AUTOMATIC PLANT CONTROL

| | NH3(LBS) | | NO2(LBS) | | NO3(LBS) | | PHOS(LBS) | |
|---|---|---|---|---|---|---|---|---|
| | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT |
| AUG 12 1973 | -7.7 % | 5142. | 0.0 % | 2. | 0.0 % | 2. | -15.0 % | 997. |
| AUG 13 1973 | 2.7 % | 7449. | 72.2 % | 2. | 98.7 % | 2. | 19.3 % | 1061. |
| AUG 14 1973 | -5.3 % | 7126. | 98.2 % | 2. | 99.7 % | 2. | -63.0 % | 1237. |
| AUG 15 1973 | -1.3 % | 9096. | 96.2 % | 2. | 99.6 % | 2. | -43.6 % | 1370. |
| AUG 16 1973 | 9.0 % | 7770. | 97.5 % | 2. | 99.4 % | 2. | -6.3 % | 1049. |
| AUG 17 1973 | 8.4 % | 7116. | 95.3 % | 2. | 99.5 % | 2. | -9.2 % | 1073. |
| AUG 18 1973 | 2.2 % | 5754. | 80.8 % | 2. | 88.1 % | 2. | 2.5 % | 1170. |
| AUG 19 1973 | -10.8 % | 5117. | 0.0 % | 2. | 0.0 % | 2. | -17.2 % | 1075. |
| AUG 20 1973 | 36.1 % | 3944. | 96.7 % | 2. | 99.6 % | 2. | 1.5 % | 1345. |
| AUG 21 1973 | 1.6 % | 7523. | 96.2 % | 2. | 99.6 % | 2. | 0.4 % | 1111. |
| AUG 22 1973 | 20.3 % | 6582. | 97.3 % | 2. | 99.6 % | 2. | -52.3 % | 1400. |
| AUG 23 1973 | 26.2 % | 6331. | 97.0 % | 2. | 99.5 % | 2. | -42.9 % | 1307. |
| AUG 24 1973 | 7.9 % | 7092. | 96.8 % | 2. | 99.4 % | 2. | -10.4 % | 1068. |
| AUG 25 1973 | -5.0 % | 6291. | 0.0 % | 2. | 0.0 % | 2. | -11.3 % | 1198. |
| AUG 26 1973 | 1.1 % | 6210. | 0.0 % | 2. | 0.0 % | 2. | -6.4 % | 935. |
| AUG 27 1973 | 15.2 % | 7037. | 95.8 % | 2. | 99.6 % | 2. | 8.7 % | 1131. |
| AUG 28 1973 | 11.6 % | 5995. | 96.4 % | 2. | 99.3 % | 2. | -52.7 % | 1356. |
| AUG 29 1973 | 14.7 % | 6401. | 97.2 % | 2. | 99.5 % | 2. | -35.9 % | 1500. |
| AUG 30 1973 | 16.9 % | 6511. | 96.9 % | 2. | 99.7 % | 2. | -38.8 % | 1310. |
| AUG 31 1973 | 25.7 % | 5563. | 97.3 % | 2. | 99.8 % | 2. | -9.6 % | 1153. |
| SEPT 1 1973 | 18.9 % | 4891. | 76.2 % | 2. | 96.4 % | 2. | -40.0 % | 1125. |
| SEPT 2 1973 | 0.0 % | 2805. | 0.0 % | 2. | 0.0 % | 2. | -29.2 % | 1075. |
| SEPT 3 1973 | 0.0 % | 2823. | 0.0 % | 2. | 0.0 % | 2. | -5.1 % | 1061. |
| SEPT 4 1973 | 20.0 % | 4361. | 90.9 % | 2. | 99.1 % | 2. | -25.6 % | 1284. |
| SEPT 5 1973 | 33.3 % | 5394. | 97.1 % | 2. | 99.5 % | 2. | -43.0 % | 1353. |
| SEPT 6 1973 | 13.9 % | 6268. | 96.8 % | 2. | 99.5 % | 2. | -5.7 % | 863. |
| SEPT 7 1973 | 6.1 % | 6301. | 78.2 % | 25. | 66.4 % | 187. | -38.6 % | 1189. |
| SEPT 8 1973 | 15.7 % | 5089. | 0.0 % | 2. | 0.0 % | 2. | -30.3 % | 1052. |
| SEPT 9 1973 | -17.7 % | 3814. | 25.0 % | 2. | 93.0 % | 2. | -33.2 % | 1194. |
| SEPT 10 1973 | 22.3 % | 4503. | 94.0 % | 3. | 99.3 % | 2. | -8.3 % | 1334. |
| SEPT 11 1973 | 9.2 % | 6075. | 94.9 % | 3. | 99.7 % | 2. | -45.8 % | 1266. |

AUG 12 1973 TO SEPT 11 1973 PLANT AIR CONSUMPTION AUTOMATIC PLANT CONTROL
AIRFLOWS IN CUBIC FEET ASSUMED COST - $.000095/CF

| | AIRFLOW#1 | AIRFLOW#2 | AIRFLOW#3 | AIRFLOW#4 | TOTAL | COST |
|---|---|---|---|---|---|---|
| AUG 12 1973 | 2974167. | 1193103. | 3054780. | 2757757. | 9979807. | $ 948.08 |
| AUG 13 1973 | 3068177. | 1228392. | 3137245. | 2632067. | 10065881. | $ 956.26 |
| AUG 14 1973 | 3309731. | 1370638. | 3414091. | 2454879. | 10549339. | $ 1002.19 |
| AUG 15 1973 | 3430249. | 1383687. | 3533688. | 2408570. | 10756194. | $ 1021.84 |
| AUG 16 1973 | 3507795. | 1508955. | 3649445. | 2387179. | 11053374. | $ 1050.07 |
| AUG 17 1973 | 3305319. | 1390726. | 3418813. | 2236073. | 10350931. | $ 983.34 |
| AUG 18 1973 | 2922345. | 1180451. | 3011929. | 1970498. | 9085223. | $ 863.10 |
| AUG 19 1973 | 2357687. | 852135. | 2436413. | 1627886. | 7274121. | $ 691.04 |
| AUG 20 1973 | 2914215. | 1187702. | 2973303. | 1955358. | 9030578. | $ 857.90 |
| AUG 21 1973 | 3276073. | 1346496. | 3365299. | 2219603. | 10207471. | $ 969.71 |
| AUG 22 1973 | 3098700. | 1216564. | 3180275. | 2123095. | 9618634. | $ 913.77 |
| AUG 23 1973 | 3014951. | 1195162. | 3092807. | 2077042. | 9379962. | $ 891.10 |
| AUG 24 1973 | 3356597. | 1388529. | 3447277. | 2265579. | 10457982. | $ 993.51 |
| AUG 25 1973 | 3188579. | 1320872. | 3296171. | 2142173. | 9947795. | $ 945.04 |
| AUG 26 1973 | 2444831. | 1192552. | 2544513. | 1684910. | 7866806. | $ 747.35 |
| AUG 27 1973 | 2936301. | 1642584. | 2985661. | 1924833. | 9489379. | $ 901.49 |
| AUG 28 1973 | 3339000. | 1803914. | 3375713. | 2084171. | 10602798. | $ 1007.27 |
| AUG 29 1973 | 3393561. | 1832402. | 3425005. | 2127655. | 10778623. | $ 1023.97 |
| AUG 30 1973 | 3682953. | 2039544. | 3764160. | 2299303. | 11785960. | $ 1119.67 |
| AUG 31 1973 | 4001785. | 2186277. | 4057007. | 2452203. | 12697272. | $ 1206.24 |
| SEPT 1 1973 | 3243780. | 1770578. | 3349081. | 1941840. | 10305279. | $ 979.00 |
| SEPT 2 1973 | 2371865. | 1075528. | 2484417. | 1464660. | 7396470. | $ 702.66 |
| SEPT 3 1973 | 2427375. | 1101258. | 2535453. | 1551255. | 7615341. | $ 723.46 |
| SEPT 4 1973 | 3102161. | 1557895. | 3245383. | 2128367. | 10033806. | $ 953.21 |
| SEPT 5 1973 | 3676597. | 2089570. | 3902103. | 3145081. | 12813351. | $ 1217.27 |
| SEPT 6 1973 | 3785629. | 2032197. | 3966399. | 3304593. | 13088818. | $ 1243.44 |
| SEPT 7 1973 | 3730001. | 2289099. | 3906450. | 3365717. | 13291267. | $ 1262.67 |
| SEPT 8 1973 | 3351973. | 2386481. | 3480167. | 2564599. | 11783220. | $ 1119.41 |
| SEPT 9 1973 | 2506517. | 1611614. | 2592545. | 1826472. | 8537148. | $ 811.03 |
| SEPT 10 1973 | 3281149. | 2605057. | 3414979. | 2373963. | 11675148. | $ 1109.14 |
| SEPT 11 1973 | 3685737. | 3168753. | 3858093. | 2628067. | 13340650. | $ 1267.36 |
| TOTAL | 98685584. | 50148608. | 101898464. | 70125248. | 320857856. | $ 30481.52 |

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AUG  12 1973  TO  SEPT 11 1973        MONTHLY EFFICIENCY SUMMARY        AUTOMATIC PLANT CONTROL


                        PRIMARY                  SECONDARY                  CHLORINATOR
                  AVE         STD       AVE         STD        AVE       STD
SS                47.7 %      12.3 %           75.3 %      10.1 %      78.1 %      8.0 %
BOD5              25.8 %      17.5 %           88.3 %       4.8 %      84.6 %      5.8 %
TOC               20.0 %       7.9 %           67.8 %       5.9 %      66.7 %      7.3 %
COD               32.5 %      11.4 %           75.4 %       6.7 %      74.6 %      5.2 %


AUG  12 1973  TO  SEPT 11 1973        RESPIRATION SUMMARY        AUTOMATIC PLANT CONTROL


  UNITS - LBS LOADING / 1000 CUBIC FEET OF AERATOR TANKAGE

                     SS          BOD          TOC          COD

  AVE              18.89        39.26        21.42        58.92

  STD               3.86        15.81         3.09        12.44
```

# APPENDIX C.3
## MLSS DATA

```
SEPT 16 1973  TO  OCT  16 1973          PROCESS DATA SUMMARY               AUTOMATIC PLANT CONTROL

         DESCRIPTION                   AVE          MIN            MAX             STD        UNITS

    TOTAL PLANT FLOW                  25.95          4.86          48.62            4.69      MGD
    LOS ALTOS FLOW                   SENSOR NOT OPERABLE
    MT. VIEWFLOW                     SENSOR NOT OPERABLE
    P H                                7.25          6.16           8.54            0.20
    D O #1                             1.01          0.10           3.15            0.38      MG/LITER
    D O #2                             1.02          0.10           5.11            0.39      MG/LITER
    D O #3                             0.53          0.10           2.70            0.31      MG/LITER
    D O #4                             1.76          0.47           5.00            0.83      MG/LITER
    AIRFLOW #1                      2626.91        531.41        3914.88          650.22      CFM
    AIRFLOW #2                      1585.56         24.42        3046.88          732.82      CFM
    AIRFLOW #3                      2730.44        306.81        4087.38          687.80      CFM
    AIRFLOW #4                      1927.09        619.41        3132.63          514.27      CFM
    TH #1 FLOW                        17.33          0.0           60.61           15.42      GPM
    TH #1 DENSITY                      4.83          0.0           10.17            2.74      PERCENT
    TH #2 FLOW                        11.89          0.0           60.77           12.95      GPM
    TH #2 DENSITY                      3.43          0.0            6.52            1.76      PERCENT
    TH #3 FLOW                        12.68          0.0           61.07           14.47      GPM
    TH #3 DENSITY                    NO VALID DATA
    TH #4 FLOW                         0.40          0.0           48.48            3.45      GPM
    TH #4 DENSITY                      5.89          3.85           5.92            0.14      PERCENT
    RAS FLOW                          11.02          0.70          25.06            2.60      MGD
    WAS FLOW                           0.46          0.00           1.59            0.24      MGD
    MLSS                            1557.21        100.00        2052.00          196.27      MG/LITER
    MLSS #2                         1553.05        985.69        3026.25          184.73      MG/LITER
    CHLORINE #1 RESIDUAL               0.0           0.0            0.0             0.0       MG/LITER
    CHLORINE FLOW #1                 449.67          0.0         2058.00          490.95      LB/DAY
    CHLORINE FLOW #2                   0.0           0.0            0.0             0.0       LB/DAY
    CHLORINE FLOW #3                   0.0           0.0            0.0             0.0       LB/DAY
    CHLORINE #2 RESIDUAL               0.0           0.0            0.0             0.0       MG/LITER
    SULFUR DIOXIDE FLOW                0.0           0.0            0.0             0.0       LB/DAY
    SPARE                              0.0           0.0            0.0             0.0
    SPARE                            NO VALID DATA
```

SEPT 16 1973 TO OCT 16 1973 LOADING DATA SUMMARY AUTOMATIC PLANT CONTROL

| | SS(LBS) | | BOD(LBS) | | TOC(LBS) | | COD(LBS) | |
|---|---|---|---|---|---|---|---|---|
| | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT | %REMOVED | EFFLUENT |
| SEPT 16 1973 | 84.5 % | 3952. | 82.2 % | 4311. | 60.6 % | 6646. | 72.8 % | 15627. |
| SEPT 17 1973 | 79.2 % | 6499. | 86.8 % | 3777. | 55.9 % | 9139. | 73.7 % | 16247. |
| SEPT 18 1973 | 76.2 % | 6329. | 90.9 % | 2572. | 57.0 % | 9392. | 73.3 % | 15925. |
| SEPT 19 1973 | 73.7 % | 6202. | 86.0 % | 4201. | 55.1 % | 8803. | 81.4 % | 11804. |
| SEPT 20 1973 | 65.8 % | 12105. | 88.4 % | 3697. | 53.3 % | 10784. | 78.7 % | 18927. |
| SEPT 21 1973 | 69.5 % | 7817. | 88.2 % | 5471. | 64.0 % | 8685. | 74.8 % | 19324. |
| SEPT 22 1973 | 80.9 % | 5860. | 86.0 % | 4102. | 56.4 % | 6641. | 75.5 % | 15039. |
| SEPT 23 1973 | 79.0 % | 5783. | 92.9 % | 2034. | 67.8 % | 5783. | 69.2 % | 14757. |
| SEPT 24 1973 | 77.4 % | 5870. | 81.1 % | 6773. | 67.7 % | 7224. | 69.9 % | 17384. |
| SEPT 25 1973 | 82.7 % | 5103. | 86.6 % | 5724. | 46.1 % | 9096. | 74.5 % | 18635. |
| SEPT 26 1973 | 78.4 % | 5493. | 88.7 % | 5010. | 59.8 % | 8569. | 100.0 % | 0. |
| SEPT 27 1973 | 62.6 % | 7415. | 88.8 % | 3795. | 51.2 % | 8941. | 100.0 % | 0. |
| SEPT 28 1973 | 71.3 % | 7661. | 87.5 % | 4990. | 62.0 % | 6566. | 100.0 % | 0. |
| SEPT 29 1973 | 74.6 % | 6627. | 76.3 % | 5592. | 56.7 % | 8077. | 100.0 % | 0. |
| SEPT 30 1973 | 72.6 % | 4704. | 80.7 % | 6381. | 65.0 % | 5727. | 100.0 % | 0. |
| OCT 1 1973 | 74.9 % | 5918. | 77.3 % | 6965. | 69.1 % | 6601. | 100.0 % | 0. |
| OCT 2 1973 | 73.8 % | 7341. | 79.7 % | 9221. | 53.2 % | 8488. | 80.8 % | 17663. |
| OCT 3 1973 | 70.4 % | 8947. | 80.4 % | 6711. | 69.0 % | 8053. | 68.3 % | 20803. |
| OCT 4 1973 | 76.6 % | 7435. | 88.5 % | 5272. | 69.5 % | 6534. | 75.0 % | 18249. |
| OCT 5 1973 | 64.7 % | 11881. | 88.8 % | 5111. | 54.8 % | 10536. | 70.6 % | 20399. |
| OCT 6 1973 | 67.7 % | 10980. | 88.2 % | 5038. | 62.4 % | 8827. | 69.8 % | 19162. |
| OCT 7 1973 | 77.6 % | 7313. | 72.7 % | 8908. | 54.8 % | 9307. | 63.4 % | 15733. |
| OCT 8 1973 | 78.2 % | 8483. | 80.7 % | 7634. | 53.0 % | 11075. | 72.4 % | 20972. |
| OCT 9 1973 | 84.4 % | 6525. | 83.5 % | 7830. | 60.4 % | 8389. | 72.3 % | 16778. |
| OCT 10 1973 | 67.2 % | 9309. | 91.9 % | 2997. | 62.7 % | 9309. | 70.0 % | 17028. |
| OCT 11 1973 | 72.4 % | 6537. | 41.8 % | 8655. | 68.5 % | 6537. | 68.8 % | 13524. |
| OCT 12 1973 | 80.5 % | 4980. | 84.3 % | 2445. | 71.0 % | 4527. | 52.4 % | 19919. |
| OCT 13 1973 | 82.5 % | 3841. | 93.7 % | 1536. | 82.3 % | 2987. | 82.1 % | 10028. |
| OCT 14 1973 | 89.5 % | 2291. | 94.5 % | 926. | 82.4 % | 2189. | 84.9 % | 6414. |
| OCT 15 1973 | 75.0 % | 8331. | 90.2 % | 3030. | 69.8 % | 6688. | 75.5 % | 18496. |
| OCT 16 1973 | 74.3 % | 8385. | 89.3 % | 3311. | 71.6 % | 6544. | 74.3 % | 17003. |

```
SEPT 16 1973  TO  OCT  16 1973          LOADING DATA SUMMARY               AUTOMATIC PLANT CONTROL

                       NH3(LBS)                NO2(LBS)               NO3(LBS)                PHOS(LBS)

                  %REMOVED|EFFLUENT      %REMOVED|EFFLUENT      %REMOVED|EFFLUENT       %REMOVED|EFFLUENT

SEPT 16 1973          0.0 %      2964.      0.0 %        4.       0.0 %         2.     -11.2 %      1121.
SEPT 17 1973         15.1 %      4569.     88.5 %        6.      99.6 %         2.     -49.0 %      1507.
SEPT 18 1973          9.5 %      5819.     96.4 %        4.      99.7 %         2.     -33.9 %      1323.
SEPT 19 1973         22.2 %      6302.     94.4 %        6.      99.7 %         2.     -33.6 %      1240.
SEPT 20 1973          8.8 %      6823.     88.2 %        9.      99.7 %         2.     -41.5 %      1298.
SEPT 21 1973         22.2 %      6840.     97.8 %        2.      97.5 %        22.     -36.4 %      1303.
SEPT 22 1973         -8.0 %      5274.     94.4 %        2.       0.0 %         2.     -19.9 %      1250.
SEPT 23 1973         -2.4 %      4288.     80.0 %        2.      93.3 %         2.     -20.8 %      1206.
SEPT 24 1973          8.0 %      5193.     93.3 %        2.      99.6 %         2.     -32.7 %      1366.
SEPT 25 1973          5.5 %      5768.     95.1 %        9.      99.3 %         2.     -35.7 %      1298.
SEPT 26 1973          7.0 %      5823.     87.9 %        9.      99.5 %         2.     -19.7 %      1296.
SEPT 27 1973          4.4 %      6106.     98.2 %        7.      99.4 %         2.     -16.0 %      1204.
SEPT 28 1973          1.2 %      6938.     93.7 %       11.      98.9 %         2.       8.8 %      1357.
SEPT 29 1973          4.3 %      7808.     90.3 %        6.      96.0 %         2.     -18.1 %      1350.
SEPT 30 1973         14.9 %      4091.     77.8 %        4.       0.0 %         2.     -11.2 %      1121.
OCT   1 1973          3.8 %      5804.     93.0 %        7.      99.3 %         2.     -37.0 %      1332.
OCT   2 1973          1.8 %      8923.     97.1 %        5.      89.6 %        69.      18.3 %      1246.
OCT   3 1973         -3.6 %      8970.     91.8 %        9.      99.4 %         2.     -27.3 %      1521.
OCT   4 1973         -3.1 %      9057.     93.4 %        9.      99.6 %         2.     -26.8 %      1397.
OCT   5 1973         -8.9 %      6837.     91.2 %        7.       0.0 %         2.       1.6 %      1258.
OCT   6 1973         56.9 %      6674.      0.0 %        2.       0.0 %         2.      -7.8 %      1369.
OCT   7 1973        -32.4 %      5429.      0.0 %        2.       0.0 %         2.     -22.7 %      1330.
OCT   8 1973         14.9 %      4713.     75.0 %        7.      99.6 %         2.      -3.8 %      1173.
OCT   9 1973         20.9 %      6175.     98.6 %        2.      99.7 %         2.     -24.0 %      1181.
OCT  10 1973          5.3 %      8173.     91.8 %        9.      99.6 %         2.      -5.9 %      1305.
OCT  11 1973         16.3 %      7551.     94.9 %        7.      99.8 %         2.     -83.2 %      1330.
OCT  12 1973         -1.4 %      8035.     98.1 %        2.      93.6 %        18.      -5.2 %      1095.
OCT  13 1973         13.3 %      5548.     95.5 %        2.      94.1 %        11.     -11.1 %      1043.
OCT  14 1973        -21.1 %      3945.     85.3 %        1.      91.4 %         1.       0.2 %       672.
OCT  15 1973          6.4 %      6573.     96.2 %        3.      99.1 %         9.     -20.4 %      1508.
OCT  16 1973          0.1 %      7232.     96.8 %        2.      98.5 %        10.     -33.6 %      1448.
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SEPT 16 1973  TO  OCT  16 1973          PLANT AIR CONSUMPTION            AUTOMATIC PLANT CONTROL

     AIRFLOWS IN CUBIC FEET             ASSUMED COST -  $.000095/CF


                         AIRFLOW#1      AIRFLOW#2      AIRFLOW#3      AIRFLOW#4          TOTAL          COST

SEPT 16 1973              2596727.       1756222.       2758455.       1978692.        9090096.    $   863.56
SEPT 17 1973              3427263.       2673115.       3587453.       2534839.       12222670.    $  1161.15
SEPT 18 1973              4037935.       3376237.       4224330.       2894407.       14532909.    $  1380.63
SEPT 19 1973              3734079.       3011905.       3890459.       2703819.       13340262.    $  1267.32
SEPT 20 1973              3947485.       3356911.       4132541.       3023535.       14460472.    $  1373.74
SEPT 21 1973              3956011.       3333411.       4109785.       3114941.       14514148.    $  1378.84
SEPT 22 1973              3870377.       3376775.       4059677.       2685365.       13992194.    $  1329.26
SEPT 23 1973              3194263.       2409421.       3326729.       2291293.       11221706.    $  1066.06
SEPT 24 1973              3504699.       2162037.       3624815.       2836773.       12128324.    $  1152.19
SEPT 25 1973              3814107.       2763693.       3943673.       3164021.       13685494.    $  1300.12
SEPT 26 1973              4060805.       2775961.       4226139.       3281809.       14344714.    $  1362.75
SEPT 27 1973              4040201.       2413823.       4222837.       3220111.       13896972.    $  1320.21
SEPT 28 1973              4356777.       1937826.       4533905.       3207633.       14036141.    $  1333.43
SEPT 29 1973              3660155.       2030440.       3840997.       2612757.       12144349.    $  1153.71
SEPT 30 1973              2718000.       1671137.       2878763.       2042552.        9310452.    $   884.49
OCT   1 1973              3396561.       2212061.       3555635.       2445871.       11610128.    $  1102.96
OCT   2 1973              3711653.       2771499.       3894555.       2640299.       13018006.    $  1236.71
OCT   3 1973              4103336.       2552371.       4282454.       2829927.       13768088.    $  1307.97
OCT   4 1973              4061129.       3153659.       4233197.       2687317.       14135302.    $  1342.85
OCT   5 1973              4307189.       2468325.       4495343.       3352201.       14623058.    $  1389.19
OCT   6 1973              4235455.       1161802.       4462935.       3575361.       13435553.    $  1276.38
OCT   7 1973              3429617.       1037350.       3342077.       2772691.       10581734.    $  1005.26
OCT   8 1973              3957807.       1577946.       3731053.       3022055.       12288861.    $  1167.44
OCT   9 1973              3529247.       1823784.       3530621.       2536539.       11420191.    $  1084.92
OCT  10 1973              4043413.       1926114.       4151723.       2765873.       12887123.    $  1224.28
OCT  11 1973              4272625.       1716851.       4515095.       2976783.       13481354.    $  1280.73
OCT  12 1973              4554009.       1730492.       4788159.       3002979.       14075639.    $  1337.19
OCT  13 1973              4089083.       2087203.       4332989.       2683141.       13192416.    $  1253.28
OCT  14 1973              3218119.       2238527.       3359659.       2213243.       11029548.    $  1047.81
OCT  15 1973              4052925.       1480402.       4254750.       2751747.       12539824.    $  1191.28
OCT  16 1973              3388037.       1795499.       3600397.       2177845.       10961778.    $  1041.37

    TOTAL               117268880.      70782592.     121890928.      86026240.      395967744.    $ 37617.04
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```
SEPT 16 1973  TO  OCT  16 1973        MONTHLY EFFICIENCY SUMMARY        AUTOMATIC PLANT CONTROL


                      PRIMARY                SECONDARY                CHLORINATOR
                   AVE        STD        AVE        STD        AVE        STD
SS                 47.7 %     11.0 %     67.7 %     10.6 %     75.4 %      6.3 %
BOD5               25.3 %     22.4 %     88.0 %      4.3 %     84.4 %      9.5 %
TOC                22.4 %     10.7 %     61.6 %      8.9 %     62.4 %      8.6 %
COD                35.6 %     16.1 %     73.2 %      5.4 %     72.9 %      6.9 %


SEPT 16 1973  TO  OCT  16 1973        RESPIRATION SUMMARY        AUTOMATIC PLANT CONTROL


   UNITS - LBS LOADING / 1000 CUBIC FEET OF AERATOR TANKAGE

                      SS          BOD          TOC          COD

AVE                 20.14        34.99        21.83        55.80

STD                  3.63        15.08         4.71         9.73
```

# APPENDIX C.4
# MANUAL-2 DATA

```
OCT  28 1973  TO  NOV  27 1973          PROCESS DATA SUMMARY              AUTOMATIC PLANT CONTROL

     DESCRIPTION                        AVE          MIN              MAX              STD        UNITS

  TOTAL PLANT FLOW                      29.2            0.01          50.15            6.37        MGD
  LOS ALTOS FLOW                        SENSOR NOT OPERABLE
  MT. VIEWFLOW                          SENSOR NOT OPERABLE
  P H                                    7.31           5.90           8.20            0.35
  D O #1                                 0.88           0.10           3.02            0.38        MG/LITER
  D O #2                                 1.03           0.10           5.15            0.55        MG/LITER
  D O #3                                 0.94           0.10           3.90            0.53        MG/LITER
  D O #4                                 1.23           0.10           5.05            0.66        MG/LITER
  AIRFLOW #1                          2230.95         244.74        4402.75          666.39        CFM
  AIRFLOW #2                          1531.92          28.52        3241.13          563.50        CFM
  AIRFLOW #3                          1984.43           0.19        4313.75          732.96        CFM
  AIRFLOW #4                          1338.27         102.71        2829.75          525.16        CFM
  TH #1 FLOW                            NO VALID DATA
  TH #1 DENSITY                          5.92           5.10           9.30            0.27        PERCENT
  TH #2 FLOW                            NO VALID DATA
  TH #2 DENSITY                          3.11           0.0            6.14            1.01        PERCENT
  TH #3 FLOW                            15.25           0.0           51.00           23.43        GPM
  TH #3 DENSITY                          5.38           0.0            7.89            1.04        PERCENT
  TH #4 FLOW                             1.88           0.0           38.30            7.24        GPM
  TH #4 DENSITY                          5.65           0.0            5.91            0.94        PERCENT
  RAS FLOW                              12.64           4.77          18.13            1.50        MGD
  WAS FLOW                               0.78           0.00           1.69            0.16        MGD
  MLSS                                1868.88           0.62        7294.50          837.66        MG/LITER
  MLSS #2                             1480.97         548.31        2241.63          289.72        MG/LITER
  CHLORINE #1 RESIDUAL                  NO VALID DATA
  CHLORINE FLOW #1                     530.92           0.0          911.25          135.23        LB/DAY
  CHLORINE FLOW #2                      NO VALID DATA
  CHLORINE FLOW #3                      NO VALID DATA
  CHLORINE #2 RESIDUAL                  NO VALID DATA
  SULFUR DIOXIDE FLOW                   NO VALID DATA
  RESPIROMETER                          NO VALID DATA
  TOC                                  121.35           5.23         253.69           44.30        MG/LITER
```

```
OCT 28 1973  TO  NOV 27 1973          LOADING DATA SUMMARY             AUTOMATIC PLANT CONTROL

                          SS(LBS)               BOD(LBS)               TOC(LBS)               COD(LBS)
                    %REMOVED|EFFLUENT    %REMOVED|EFFLUENT    %REMOVED|EFFLUENT    %REMOVED|EFFLUENT

OCT 28 1973          100.0 %       0.     100.0 %       0.     100.0 %       0.     100.0 %       0.
OCT 29 1973           85.9 %    4674.      64.4 %   10569.      85.2 %    3963.      81.0 %   14092.
OCT 30 1973           89.1 %    6234.      55.8 %    9752.      70.3 %    6690.      77.9 %   14696.
OCT 31 1973           67.9 %    8207.      61.5 %   10805.      71.3 %    7067.      75.8 %   15047.
NOV  1 1973           77.5 %    6328.      49.0 %   11108.      63.8 %    7968.      76.9 %   14999.
NOV  2 1973           30.7 %   16254.      95.3 %    1951.      55.4 %    6734.      68.5 %   19505.
NOV  3 1973           61.1 %    7838.      95.3 %    2415.      57.7 %    6991.      67.4 %   21608.
NOV  4 1973           65.4 %    9725.      95.9 %    1776.      63.9 %    6342.      70.5 %   17125.
NOV  5 1973           56.7 %   11024.      80.6 %    8819.      69.4 %    5390.      73.1 %   18129.
NOV  6 1973           66.9 %   10695.      90.0 %    8058.      63.9 %    6467.      74.7 %   19649.
NOV  7 1973           92.4 %    6351.      82.9 %    6401.      66.3 %    7113.      67.6 %   29722.
NOV  8 1973           90.1 %    4157.      73.4 %    8418.      65.9 %    7275.      68.1 %   27282.
NOV  9 1973           93.5 %    5649.      79.7 %   11709.      69.5 %    7447.      74.1 %   21056.
NOV 10 1973           77.6 %    5647.      70.2 %   10305.      62.7 %    6588.      73.0 %   18586.
NOV 11 1973           86.2 %    4831.      85.3 %    4969.      76.2 %    5521.      78.2 %   16334.
NOV 12 1973           89.4 %    5399.      80.5 %   12473.      74.3 %    7829.      79.9 %   18898.
NOV 13 1973           74.1 %    7825.      80.5 %   12050.      58.1 %    9390.      79.7 %   17475.
NOV 14 1973           89.7 %    4714.      89.8 %    6023.      74.3 %    7333.      80.6 %   16237.
NOV 15 1973           88.5 %    6002.      87.0 %    7150.      71.7 %    8351.      82.9 %   14092.
NOV 16 1973           88.0 %    4904.      81.9 %   10012.      71.4 %    6068.      80.6 %   13653.
NOV 17 1973           68.7 %    5500.      78.9 %   11628.      53.2 %    5762.      60.1 %   14928.
NOV 18 1973           90.0 %    2746.      74.7 %   11387.      73.2 %    3995.      78.2 %   14233.
NOV 19 1973           84.4 %    7571.      84.7 %    9145.      82.4 %    4960.      93.5 %   14097.
NOV 20 1973           90.9 %    3216.      80.0 %   11577.      75.5 %    6164.      81.1 %   15811.
NOV 21 1973           84.3 %    4251.      82.9 %    5579.      81.6 %    4251.      78.0 %   16472.
NOV 22 1973           80.1 %    6321.      91.6 %    2669.      80.6 %    4682.      80.1 %   12642.
NOV 23 1973           88.5 %    4863.      89.1 %    3334.      83.7 %    3705.      87.6 %   10651.
NOV 24 1973           91.9 %    3659.      90.1 %    3064.      84.2 %    3887.      85.6 %   10519.
NOV 25 1973           90.1 %    3855.      91.2 %    2665.      80.1 %    4510.      83.4 %   12013.
NOV 26 1973           87.3 %    5286.      93.4 %    2651.      75.8 %    6437.      81.9 %   15112.
NOV 27 1973           96.0 %    5550.      95.5 %    1517.      81.1 %    5017.      90.5 %   14418.
```

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OCT  28 1973  TO  NOV  27 1973          LOADING DATA SUMMARY               AUTOMATIC PLANT CONTROL

                       NH3(LBS)               NO2(LBS)               NO3(LBS)               PHOS(LBS)

                  %REMOVED|EFFLUENT      %REMOVED|EFFLUENT      %REMOVED|EFFLUENT      %REMOVED|EFFLUENT


OCT  28 1973        100.0 %        0.    100.0 %        0.    100.0 %        0.    100.0 %        0.
OCT  29 1973         10.9 %     6275.     97.0 %        2.     99.6 %        2.     79.7 %      271.
OCT  30 1973         11.1 %     8016.     95.5 %        2.     98.7 %        2.    -14.5 %     1269.
OCT  31 1973          3.9 %     8321.     96.2 %        2.     99.5 %        2.    -25.5 %     1258.
NOV   1 1973          0.0 %     8905.     98.3 %        2.     95.3 %       23.    -12.1 %     1261.
NOV   2 1973         -1.4 %     8592.     96.9 %        2.     99.7 %        2.    -19.6 %     1358.
NOV   3 1973          1.4 %     7626.     80.0 %        2.     98.1 %        2.    -28.3 %     1218.
NOV   4 1973        -15.7 %     6237.      0.0 %        2.      0.0 %        2.     -9.5 %     1216.
NOV   5 1973         19.1 %     6737.     80.0 %        2.     99.6 %        2.    -16.2 %     1298.
NOV   6 1973          7.7 %     7462.     93.3 %        2.     93.1 %       90.    -30.0 %     1293.
NOV   7 1973         16.7 %    10161.     89.6 %       13.     64.0 %      114.      3.4 %     1229.
NOV   8 1973          2.3 %    11173.     87.8 %       13.     80.7 %      197.     -7.7 %     1195.
NOV   9 1973        -12.5 %    11555.     88.9 %       10.     26.1 %      167.    -18.0 %     1381.
NOV  10 1973        -20.0 %     9881.     84.6 %        5.     33.3 %       66.    -25.3 %     1468.
NOV  11 1973        -22.8 %     8052.     66.7 %        2.     58.3 %       46.    -22.7 %     1392.
NOV  12 1973         19.4 %     7829.     89.5 %        5.     99.1 %        3.    -29.9 %     1479.
NOV  13 1973         12.2 %     9477.     98.1 %        3.     76.1 %       55.    -20.1 %     1322.
NOV  14 1973         -1.4 %     9690.     97.8 %        3.     99.2 %        3.    -25.1 %     1398.
NOV  15 1973          1.3 %     9917.     97.1 %        3.     99.6 %        3.    -13.7 %     1451.
NOV  16 1973         -1.2 %    10366.     98.6 %        3.     99.4 %        3.    -84.4 %     1492.
NOV  17 1973          2.6 %     9690.     94.4 %        3.     98.6 %        3.    -10.7 %     1270.
NOV  18 1973         -6.0 %     6617.     94.1 %        2.     94.1 %       25.    -36.3 %     1246.
NOV  19 1973         31.9 %     6135.     94.7 %        5.     99.6 %        3.     -9.5 %     1201.
NOV  20 1973         -4.2 %     9915.     86.4 %        8.     66.9 %      126.    -42.7 %     1568.
NOV  21 1973          1.4 %     9166.     95.5 %        3.     94.4 %       53.      1.1 %     1196.
NOV  22 1973         -9.0 %     8545.     95.0 %        2.     98.7 %        2.    -23.0 %     1100.
NOV  23 1973        -10.6 %     8452.     75.0 %        2.      0.0 %        2.     11.6 %      972.
NOV  24 1973         -9.2 %     8118.     50.0 %        2.     95.0 %        2.    -12.3 %     1189.
NOV  25 1973        -14.0 %     7373.     93.5 %        2.     91.8 %        6.    -25.6 %     1098.
NOV  26 1973          0.7 %     8110.     96.8 %        3.     91.7 %       31.    -43.6 %     1339.
NOV  27 1973         12.0 %     8118.     92.8 %        6.     92.8 %       49.    -31.7 %     1045.
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OCT  28 1973  TO  NOV  27 1973               FLOW DATA SUMMARY                          AUTOMATIC PLANT CONTROL
                   PLANT      MIX LIQ      MIX LIQ
                   FLOW        SVI         SS SLD       RAS        WAS
                   (MGD)                   (MGL)       (MGL)      (MGL)

OCT  28 1973       24.10       0.0          0.0         0.0        0.0
OCT  29 1973       26.40       0.0          0.0         0.0        0.0
OCT  30 1973       26.70       0.0          0.0         0.0        0.0
OCT  31 1973       27.34       0.0          0.0         0.0        0.0
NOV   1 1973       28.10       0.0          0.0         0.0        0.0
NOV   2 1973       27.84       0.0          0.0         0.0        0.0
NOV   3 1973       25.40       0.0          0.0         0.0        0.0
NOV   4 1973       25.35       0.0          0.0         0.0        0.0
NOV   5 1973       29.37       0.0          0.0         0.0        0.0
NOV   6 1973       29.82       0.0          0.0         0.0        0.0
NOV   7 1973       30.46       0.0          0.0         0.0        0.0
NOV   8 1973       31.15       0.0          0.0         0.0        0.0
NOV   9 1973       30.79       0.0          0.0         0.0        0.0
NOV  10 1973       28.21       0.0          0.0         0.0        0.0
NOV  11 1973       27.58       0.0          0.0         0.0        0.0
NOV  12 1973       32.37       0.0          0.0         0.0        0.0
NOV  13 1973       31.27       0.0          0.0         0.0        0.0
NOV  14 1973       31.40       0.0          0.0         0.0        0.0
NOV  15 1973       31.29       0.0          0.0         0.0        0.0
NOV  16 1973       30.32       0.0          0.0         0.0        0.0
NOV  17 1973       31.40       0.0          0.0         0.0        0.0
NOV  18 1973       29.94       0.0          0.0         0.0        0.0
NOV  19 1973       31.30       0.0          0.0         0.0        0.0
NOV  20 1973       32.13       0.0          0.0         0.0        0.0
NOV  21 1973       31.85       0.0          0.0         0.0        0.0
NOV  22 1973       28.07       0.0          0.0         0.0        0.0
NOV  23 1973       27.76       0.0          0.0         0.0        0.0
NOV  24 1973       27.42       0.0          0.0         0.0        0.0
NOV  25 1973       26.92       0.0          0.0         0.0        0.0
NOV  26 1973       30.67       0.0          0.0         0.0        0.0
NOV  27 1973       28.42       0.0          0.0         0.0        0.0
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OCT  28 1973  TO  NOV  27 1973          PLANT AIR CONSUMPTION              AUTOMATIC PLANT CONTROL

     AIRFLOWS IN CUBIC FEET             ASSUMED COST - $.000095/CF


                          AIRFLOW#1     AIRFLOW#2     AIRFLOW#3     AIRFLOW#4          TOTAL            COST


OCT  28 1973               3668377.      1409535.      3804477.      2116013.      10998402.      $  1044.85
OCT  29 1973               3800539.      2001246.      3970383.      2184257.      11956425.      $  1135.86
OCT  30 1973               3200741.      1718975.      3195097.      2549115.      10663928.      $  1013.07
OCT  31 1973               3365521.      1549320.      3480145.      2515177.      10910163.      $  1036.47
NOV   1 1973               3051505.      1945542.      3129204.      2237175.      10363426.      $   984.53
NOV   2 1973               3330531.      2763239.      3823381.      2692209.      12609360.      $  1197.89
NOV   3 1973               2855839.      2747877.      3729019.      2478955.      11811690.      $  1122.11
NOV   4 1973               2806511.      2342557.      3291805.      1770785.      10211658.      $   970.11
NOV   5 1973               3656287.      2591257.      3597457.      2542165.      12387166.      $  1176.78
NOV   6 1973               3577581.      2584455.      2900880.      2012745.      11075661.      $  1052.19
NOV   7 1973               3659869.      2643877.      3293205.      2215575.      11812526.      $  1122.19
NOV   8 1973               3543589.      3281207.      3277607.      2283187.      12385590.      $  1176.63
NOV   9 1973               3590003.      2793567.      3122255.      2038661.      11544486.      $  1096.73
NOV  10 1973               3369883.      2295755.      2982539.      1707781.      10355958.      $   983.82
NOV  11 1973               2834723.      1724435.      2213370.      1222693.       7995221.      $   759.55
NOV  12 1973               3324571.      2412487.      2880189.      1661858.      10279105.      $   976.51
NOV  13 1973               3628415.      2551617.      3140599.      2056980.      11377611.      $  1080.87
NOV  14 1973               3305787.      2275143.      2775095.      1817773.      10173798.      $   966.51
NOV  15 1973               3364657.      2392501.      2431621.      1940256.      10129035.      $   962.26
NOV  16 1973               2985295.      2370867.      2385595.      1780951.       9522708.      $   904.66
NOV  17 1973               2659561.      2106639.      2616120.      1424360.       8806680.      $   836.63
NOV  18 1973               2081997.      1601317.      2011511.       920819.       6615643.      $   628.49
NOV  19 1973               2490965.      2152009.      2430027.      1377142.       8450143.      $   802.76
NOV  20 1973               2732893.      1756593.      2289783.      1634296.       8413565.      $   799.29
NOV  21 1973               3513567.      2451309.      3099201.      2295975.      11360052.      $  1079.20
NOV  22 1973               3006435.      1865004.      2100347.      1686571.       8658357.      $   822.54
NOV  23 1973               4002067.      2335641.      2479397.      2295727.      11112832.      $  1055.72
NOV  24 1973               2472840.      1559503.      1534015.      1162580.       6728938.      $   639.25
NOV  25 1973               2655609.      1451677.      1710238.      1170904.       6988428.      $   663.90
NOV  26 1973               3385021.      2348907.      2299825.      1990035.      10023788.      $   952.26
NOV  27 1973               3668799.      2360603.      2591227.      1958398.      10579027.      $  1005.01

    TOTAL                 99589712.     68384464.     88585392.     55740960.     316300289.      $ 30048.57
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OCT  28 1973  TO  NOV  27 1973         MONTHLY EFFICIENCY SUMMARY         AUTOMATIC PLANT CONTROL


                          PRIMARY                 SECONDARY
                      AVE        STD        AVE        STD        AVE        STD      CHLORINATOR
  SS                  45.4 %       19.0 %       77.4 %      12.9 %      79.8 %      13.5 %
  BOD5                 9.1 %       11.5 %       85.7 %       9.8 %      81.5 %      11.7 %
  TOC                 20.4 %       17.8 %       74.3 %       8.2 %      71.6 %       9.1 %
  COD                 27.6 %       14.4 %       76.4 %       8.5 %      76.9 %       6.6 %


OCT  28 1973  TO  NOV  27 1973         RESPIRATION SUMMARY         AUTOMATIC PLANT CONTROL


  UNITS - LBS LOADING / 1000 CUBIC FEET OF AERATOR TANKAGE

                    SS          BOD          TOC          COD

  AVE            18.48         38.4        17.45        52.26

  STD             5.32        12.48         2.95         8.37
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# APPENDIX C.5

# AIR/RAS DATA

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JAN 13 1974  TO  FEB 12 1974          PROCESS DATA SUMMARY                    AUTOMATIC PLANT CONTROL
      DESCRIPTION                  AVE          MIN             MAX             STD         UNITS
  TOTAL PLANT FLOW                26.8              0.03         52.68           10.0         MGD
  LOS ALTOS FLOW                  SENSOR NOT OPERABLE
  MT. VIEWFLOW                    SENSOR NOT OPERABLE
  P H                              6.76             4.55          8.05            0.75
  D O #1                           0.77             0.10          2.83            0.35        MG/LITER
  D O #2                           0.77             0.10          2.89            0.35        MG/LITER
  D O #3                           1.07             0.10          3.21            0.43        MG/LITER
  D O #4                           0.50             0.10          3.65            0.56        MG/LITER
  AIRFLOW #1                    1936.42            94.32       3605.50          678.23        CFM
  AIRFLOW #2                    1003.44             1.12       2477.75          685.78        CFM
  AIRFLOW #3                    1543.78             2.98       2994.63          530.72        CFM
  AIRFLOW #4                    1555.84            12.68       3651.13          631.16        CFM
  TH #1 FLOW                      14.30             0.0          60.52           18.88        GPM
  TH #1 DENSITY                    4.83             0.39          5.56            0.43        PERCENT
  TH #2 FLOW                      28.27             0.0          60.56           20.49        GPM
  TH #2 DENSITY                    3.89             0.0           6.03            1.03        PERCENT
  TH #3 FLOW                       0.76             0.0          56.06            5.09        GPM
  TH #3 DENSITY                    4.80             0.03          5.37            0.18        PERCENT
  TH #4 FLOW                      38.75             0.00         60.82           11.95        GPM
  TH #4 DENSITY                    4.07             0.41          6.47            0.97        PERCENT
  RAS FLOW                        11.52             0.36         21.17            3.53        MGD
  WAS FLOW                         0.41             0.00          1.30            0.27        MGD
  MLSS                          1576.71            33.92       2554.63          444.23        MG/LITER
  MLSS #2                       1762.99           296.55       2721.13          460.20        MG/LITER
  CHLORINE #1 RESIDUAL            NO VALID DATA
  CHLORINE FLOW #1               264.52             9.44        698.50          107.46        LB/DAY
  CHLORINE FLOW #2                NO VALID DATA
  CHLORINE FLOW #3                NO VALID DATA
  CHLORINE #2 RESIDUAL            NO VALID DATA
  SULFUR DIOXIDE FLOW             NO VALID DATA
  RESPIROMETER                     6.01             0.0          95.43            6.49        MG/LITER
  TOC                             NO VALID DATA
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JAN  13 1974  TO  FEB  12 1974          LOADING DATA SUMMARY             AUTOMATIC PLANT CONTROL

                          SS(LBS)               BOD(LBS)               TOC(LBS)               COD(LBS)

                     %REMOVED|EFFLUENT    %REMOVED|EFFLUENT    %REMOVED|EFFLUENT    %REMOVED|EFFLUENT

JAN  13 1974            87.0 %      4790.    79.3 %     11085.    79.6 %      4334.    82.0 %     13685.
JAN  14 1974            81.8 %      7638.    83.3 %      9820.    77.1 %      6001.    82.0 %     15822.
JAN  15 1974            87.5 %      5979.    69.1 %      4728.    79.1 %      4891.    81.6 %     15761.
JAN  16 1974            63.3 %     10414.    78.0 %     13364.    72.6 %      5785.    63.8 %     22853.
JAN  17 1974            70.2 %      7503.    78.6 %      9967.    75.4 %      4287.    76.5 %     13933.
JAN  18 1974            76.3 %      8118.    87.2 %      7002.    67.1 %      6596.    80.7 %     14460.
JAN  19 1974            70.4 %     10119.    85.9 %      6881.    62.7 %      6971.    63.0 %     19113.
JAN  20 1974            68.0 %      8191.    75.9 %     10934.    71.0 %      4095.    75.6 %     12900.
JAN  21 1974            61.0 %      6672.    78.7 %      9578.    79.8 %      4527.    73.0 %     17870.
JAN  22 1974            60.5 %     12114.    91.0 %      3991.    69.8 %      6888.    69.1 %     20665.
JAN  23 1974            55.3 %      9596.    91.9 %      3016.    58.4 %      7312.    70.9 %     17594.
JAN  24 1974            75.1 %     10223.    85.9 %      3346.    54.4 %      8365.    61.5 %     17891.
JAN  25 1974            73.9 %     10484.    86.2 %      4149.    58.1 %      6915.    74.7 %     18292.
JAN  26 1974           100.0 %         0.   100.0 %         0.   100.0 %         0.   100.0 %         0.
JAN  27 1974            98.0 %      4625.    91.2 %      2482.    72.2 %      4866.    77.3 %     12484.
JAN  28 1974            87.5 %      5161.    90.0 %      3734.    76.3 %      4685.    77.2 %     16655.
JAN  29 1974            96.1 %      5417.    93.3 %      2643.    80.5 %      3781.    83.5 %     13144.
JAN  30 1974            87.6 %      4382.    92.2 %      2892.    66.3 %      7449.    80.3 %     12926.
JAN  31 1974            84.5 %      4819.    90.6 %      3154.    68.1 %      6572.    84.4 %     12974.
FEB   1 1974            88.1 %      3508.    89.8 %      3420.    63.4 %      6577.    80.1 %     10962.
FEB   2 1974            79.3 %      5810.    82.4 %      3314.    61.2 %      4953.    64.6 %     12191.
FEB   3 1974            86.7 %      2837.    92.7 %      1915.    70.4 %      4255.    79.4 %      9574.
FEB   4 1974            91.0 %      3020.    92.0 %      2848.    70.4 %      5178.    81.9 %     10355.
FEB   5 1974            94.4 %      3715.    95.2 %      2229.    79.3 %      6337.    88.0 %     12674.
FEB   6 1974            81.2 %      4884.    90.0 %      3063.    70.4 %      5328.    77.0 %     14651.
FEB   7 1974            86.3 %      4258.    90.4 %      3321.    70.7 %      7238.    77.5 %     14476.
FEB   8 1974            76.6 %      2353.    69.9 %      2599.    81.4 %      4712.    73.7 %     17135.
FEB   9 1974            73.9 %      6629.     0.0 %      2273.    76.8 %      4356.    51.6 %     14584.
FEB  10 1974            92.9 %      5665.    89.7 %      2724.    77.2 %      3990.    74.0 %     13878.
FEB  11 1974            83.7 %      6594.    89.9 %      3891.    77.0 %      4972.    75.9 %     16160.
FEB  12 1974            90.9 %      7135.    88.2 %      4376.    72.7 %      5945.    73.6 %     18038.
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JAN 13 1974  TO  FEB 12 1974           LOADING DATA SUMMARY                     AUTOMATIC PLANT CONTROL

                         NH3(LBS)              NO2(LBS)              NO3(LBS)              PHOS(LBS)

                    %REMOVED|EFFLUENT     %REMOVED|EFFLUENT     %REMOVED|EFFLUENT     %REMOVED|EFFLUENT

JAN 13 1974            -7.8 %    7869.      0.0 %        2.   -5899.9 %      137.    -14.6 %      1254.
JAN 14 1974             9.7 %    8866.     88.9 %        3.      99.2 %        3.     -7.8 %      1514.
JAN 15 1974            24.5 %   10054.     92.9 %        5.      99.7 %        3.    -52.4 %      1739.
JAN 16 1974            -9.5 %   13307.     68.7 %       14.      80.0 %      130.      2.1 %      1360.
JAN 17 1974             9.5 %   10162.     94.1 %        3.      99.7 %        3.    -14.9 %      1340.
JAN 18 1974            18.6 %    8879.     75.0 %        3.      99.6 %        3.    -20.0 %      1370.
JAN 19 1974           -23.4 %    8882.     75.0 %        2.      99.5 %        2.    -21.1 %      1225.
JAN 20 1974            -8.6 %    6450.      0.0 %        2.      98.0 %        2.    -33.7 %      1177.
JAN 21 1974            22.0 %    7625.     87.5 %        2.      99.6 %        2.    -18.9 %      1275.
JAN 22 1974            -8.3 %   12352.     92.3 %        2.      99.8 %        2.    -35.7 %      1354.
JAN 23 1974            20.8 %    8682.     80.0 %        7.      99.7 %        2.    -11.6 %      1211.
JAN 24 1974            -4.4 %    5460.    100.0 %        0.     100.0 %        0.    -29.3 %      1231.
JAN 25 1974            14.9 %    8923.    100.0 %        0.     100.0 %        0.    -26.2 %      1126.
JAN 26 1974           100.0 %       0.    100.0 %        0.     100.0 %        0.    100.0 %         0.
JAN 27 1974           100.0 %       0.    100.0 %        0.     100.0 %        0.    -19.5 %       823.
JAN 28 1974           100.0 %       0.    100.0 %        0.     100.0 %        0.    -17.9 %      1064.
JAN 29 1974           100.0 %       0.    100.0 %        0.     100.0 %        0.    -21.2 %      1209.
JAN 30 1974             8.7 %    9202.     60.0 %        0.      91.1 %       77.     -4.3 %       960.
JAN 31 1974            -8.7 %   10953.    100.0 %        0.     100.0 %        0.    100.0 %         0.
FEB  1 1974             3.1 %    8112.     69.2 %        0.      52.6 %      197.     -8.1 %      1232.
FEB  2 1974            -6.4 %    6324.     40.0 %        6.      61.5 %       48.     11.7 %       867.
FEB  3 1974           -69.5 %    3546.      0.0 %        2.       0.0 %        2.    -10.0 %       978.
FEB  4 1974             7.6 %    3991.     50.0 %       11.      76.9 %       97.     -2.7 %      1219.
FEB  5 1974            31.9 %    3278.     44.4 %       22.      62.1 %      240.      2.6 %      1224.
FEB  6 1974             2.3 %    9324.     50.0 %       11.      71.9 %      244.     -1.0 %      1121.
FEB  7 1974            24.1 %    8728.     64.3 %       11.     100.0 %        0.     -6.5 %      1043.
FEB  8 1974             0.0 %   12423.     58.3 %       11.      56.1 %      193.     -8.9 %       921.
FEB  9 1974             1.1 %    8807.     98.0 %        0.      68.7 %       95.    -25.9 %       966.
FEB 10 1974            -1.7 %    6440.     97.9 %        0.      75.8 %       25.    -14.0 %       793.
FEB 11 1974             8.8 %    7954.     76.4 %        6.      83.7 %       88.      4.2 %       901.
FEB 12 1974             5.6 %    8205.     93.1 %        3.      87.6 %       51.     -5.0 %       976.
```

JAN 13 1974 TO FEB 12 1974 FLOW DATA SUMMARY AUTOMATIC PLANT CONTROL

| | PLANT FLOW (MGD) | MIX LIQ SVI | MIX LIQ SS SLD (MGL) | RAS (MGL) | WAS (MGL) |
|---|---|---|---|---|---|
| JAN 13 1974 | 27.35 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 14 1974 | 32.71 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 15 1974 | 32.58 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 16 1974 | 34.69 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 17 1974 | 32.13 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 18 1974 | 30.42 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 19 1974 | 26.96 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 20 1974 | 24.55 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 21 1974 | 28.57 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 22 1974 | 28.48 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 23 1974 | 27.40 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 24 1974 | 27.86 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 25 1974 | 26.75 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 26 1974 | 23.10 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 27 1974 | 21.41 | 77.83 | 2182.08 | 5962.50 | 1994.33 |
| JAN 28 1974 | 26.33 | 67.50 | 1958.75 | 8272.50 | 2166.67 |
| JAN 29 1974 | 26.16 | 64.42 | 2103.93 | 7580.00 | 2096.67 |
| JAN 30 1974 | 26.27 | 0.0 | 0.0 | 0.0 | 0.0 |
| JAN 31 1974 | 26.27 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 1 1974 | 26.29 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 2 1974 | 22.84 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 3 1974 | 21.26 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 4 1974 | 25.87 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 5 1974 | 26.20 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 6 1974 | 26.62 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 7 1974 | 25.53 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 8 1974 | 25.68 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 9 1974 | 22.71 | 0.0 | 0.0 | 0.0 | 0.0 |
| FEB 10 1974 | 20.80 | 72.50 | 1640.75 | 5840.83 | 1663.33 |
| FEB 11 1974 | 25.92 | 69.42 | 1587.75 | 7890.00 | 1584.33 |
| FEB 12 1974 | 26.32 | 65.75 | 1635.25 | 5631.66 | 1453.75 |

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JAN 13 1974 TO FEB 12 1974 | PLANT AIR CONSUMPTION | AUTOMATIC PLANT CONTROL

AIRFLOWS IN CUBIC FEET | ASSUMED COST - $.000095/CF

| | AIRFLOW#1 | AIRFLOW#2 | AIRFLOW#3 | AIRFLOW#4 | TOTAL | COST |
|---|---|---|---|---|---|---|
| JAN 13 1974 | 2346395. | 1093248. | 1562739. | 1798851. | 6802232. | $ 646.21 |
| JAN 14 1974 | 3115019. | 55824. | 1954440. | 2633351. | 7826534. | $ 743.52 |
| JAN 15 1974 | 3601067. | 113170. | 2146035. | 3220513. | 9080788. | $ 862.67 |
| JAN 16 1974 | 3652297. | 124901. | 2526536. | 2947653. | 9281975. | $ 881.79 |
| JAN 17 1974 | 3923299. | 114331. | 2393607. | 2995367. | 9426603. | $ 895.53 |
| JAN 18 1974 | 4130881. | 115551. | 2562677. | 3111057. | 9920165. | $ 942.42 |
| JAN 19 1974 | 4244947. | 337303. | 2004565. | 3510699. | 10097763. | $ 959.29 |
| JAN 20 1974 | 3366617. | 97508. | 2921133. | 2544921. | 8943265. | $ 849.61 |
| JAN 21 1974 | 3424273. | 62643. | 2273323. | 2409465. | 9173703. | $ 871.50 |
| JAN 22 1974 | 3375061. | 639000. | 2376501. | 2458235. | 9639896. | $ 915.79 |
| JAN 23 1974 | 2763011. | 2056304. | 2915241. | 2116590. | 9851446. | $ 935.89 |
| JAN 24 1974 | 2855077. | 2248505. | 2757269. | 1782377. | 9707548. | $ 922.22 |
| JAN 25 1974 | 2995113. | 2163551. | 2701649. | 1784555. | 9648868. | $ 916.64 |
| JAN 26 1974 | 2498071. | 2296000. | 2430943. | 1576157. | 9301270. | $ 883.62 |
| JAN 27 1974 | 1825926. | 1633737. | 1487029. | 1400255. | 6346947. | $ 602.96 |
| JAN 28 1974 | 2364899. | 1840903. | 2176327. | 1302131. | 7684250. | $ 730.00 |
| JAN 29 1974 | 2549849. | 1966463. | 2028466. | 1918808. | 8463586. | $ 804.04 |
| JAN 30 1974 | 2155445. | 1905303. | 1850633. | 1742963. | 7654243. | $ 727.15 |
| JAN 31 1974 | 2371015. | 1890046. | 1791703. | 2050010. | 8142774. | $ 773.56 |
| FEB 1 1974 | 2442597. | 2108750. | 1863512. | 2104727. | 8519685. | $ 809.37 |
| FEB 2 1974 | 2165665. | 2210613. | 2003797. | 1947940. | 8328015. | $ 791.16 |
| FEB 3 1974 | 1690431. | 1711731. | 1333508. | 1622183. | 6357853. | $ 604.00 |
| FEB 4 1974 | 2300997. | 1955835. | 1814620. | 1856966. | 7928421. | $ 753.20 |
| FEB 5 1974 | 2285409. | 1715270. | 1907455. | 1778989. | 7687153. | $ 730.28 |
| FEB 6 1974 | 2467012. | 1760927. | 2136675. | 1227059. | 7591573. | $ 721.20 |
| FEB 7 1974 | 2701309. | 1911554. | 2255621. | 2529175. | 9397659. | $ 892.78 |
| FEB 8 1974 | 2888893. | 2234715. | 1627155. | 3124823. | 9875586. | $ 938.18 |
| FEB 9 1974 | 2762811. | 1933556. | 1839476. | 2208327. | 8435470. | $ 801.37 |
| FEB 10 1974 | 1863071. | 1630795. | 1974354. | 1791851. | 7260071. | $ 689.71 |
| FEB 11 1974 | 2549292. | 2549820. | 2659911. | 2672701. | 10459734. | $ 993.67 |
| FEB 12 1974 | 2826419. | 2469603. | 2657175. | 2815313. | 10768510. | $ 1023.01 |
| TOTAL | 86443016. | 44703520. | 68914400. | 69453040. | 269603328. | $ 25612.30 |

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JAN 12 1974  TO  FEB 12 1974         MONTHLY EFFICIENCY SUMMARY        AUTOMATIC PLANT CONTROL


                           PRIMARY                    SECONDARY                   CHLORINATOR
                      AVE         STD        AVE         STD        AVE        STD
SS                    54.5 %      10.1 %     77.0 %      10.2 %     79.6 %     9.4 %
BOD5                  20.0 %      14.3-%     86.7 %       4.0 %     87.6 %     6.0 %
TOC                   24.4 %      12.3 %     72.5 %       6.3 %     71.3 %     7.3 %
COD                   25.4 %       6.2 %     75.8 %       7.4 %     75.2 %     7.0 %


JAN 12 1974  TO  FEB 12 1974         RESPIRATION SUMMARY               AUTOMATIC PLANT CONTROL


  UNITS - LBS LOADING / 1000 CUBIC FEET OF AERATOR TANKAGE

                    SS         BOD         TOC         COD

  AVE             15.26       31.60       12.97       41.18

  STD              3.81       10.00        2.14        5.69
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# APPENDIX C.6

# RESP/RAS DATA

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FEB  13 1974  TO  MAR  12 1974           PROCESS DATA SUMMARY                 AUTOMATIC PLANT CONTROL

        DESCRIPTION                         AVE          MIN             MAX                 STD        UNITS

     TOTAL PLANT FLOW                      24.72            0.12           51.28               8.79       MGD
     LOS ALTOS FLOW                         SENSOR NOT OPERABLE
     MT. VIEWFLOW                           SENSOR NOT OPERABLE
     P H                                    6.94            6.91            6.96               0.05
     D O #1                                  .816           0.10            3.61                .434      MG/LITER
     D O #2                                  .828           0.10            3.64                .456      MG/LITER
     D O #3                                  .928           0.14            2.77                .389      MG/LITER
     D O #4                                  .861           0.16            3.72                .644      MG/LITER
     AIRFLOW #1                           1799.62          42.50         3435.88             624.74       CFM
     AIRFLOW #2                           1470.58         155.27         2947.13             479.68       CFM
     AIRFLOW #3                           1715.43           1.12         3805.88             680.79       CFM
     AIRFLOW #4                           1812.60          16.03         3577.13             734.18       CFM
     TH #1 FLOW                             NO VALID DATA
     TH #1 DENSITY                          5.03            0.33            5.48               0.09       PERCENT
     TH #2 FLOW                            35.68            0.0            60.66              10.81       GPM
     TH #2 DENSITY                          4.29            0.25            7.25               0.74       PERCENT
     TH #3 FLOW                             4.50            0.0            60.02               9.41       GPM
     TH #3 DENSITY                          5.07            0.39            9.47               0.96       PERCENT
     TH #4 FLOW                            35.37            0.0            60.49              14.38       GPM
     TH #4 DENSITY                          3.95            0.01            7.69               1.27       PERCENT
     RAS FLOW                              12.77            6.31           20.34               2.95       MGD
     WAS FLOW                               0.57            0.00            2.05               0.57       MGD
     MLSS                                 1400.45         210.45         2022.88             292.81       MG/LITER
     MLSS #2                              1545.03        1026.69         1953.06             220.82       MG/LITER
     CHLORINE #1 RESIDUAL                   NO VALID DATA
     CHLORINE FLOW #1                     1478.68           8.04         4847.75             892.44       LB/DAY
     CHLORINE FLOW #2                       NO VALID DATA
     CHLORINE FLOW #3                       NO VALID DATA
     CHLORINE #2 RESIDUAL                   NO VALID DATA
     SULFUR DIOXIDE FLOW                    NO VALID DATA
     RESPIROMETER                          11.68            0.10           25.29               6.10       MG/LITER
     TOC                                   59.69            0.0           253.03              36.41       MG/LITER
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FEB  13 1974  TO  MAR  12 1974          LOADING DATA SUMMARY                AUTOMATIC PLANT CONTROL

                           SS(LBS)              BOD(LBS)              TOC(LBS)              COD(LBS)

                      %REMOVED|EFFLUENT    %REMOVED|EFFLUENT    %REMOVED|EFFLUENT    %REMOVED|EFFLUENT

FEB  13 1974              75.7 %      8403.    89.4 %      3443.    65.7 %      6969.    76.6 %     14962.
FEB  14 1974              74.0 %      6872.    81.6 %      7371.    61.0 %      8121.    96.8 %      2291.
FEB  15 1974              76.9 %      5078.    87.9 %      3900.    58.4 %      7516.    72.1 %     16454.
FEB  16 1974              92.8 %      2544.    91.4 %      2250.    72.7 %      4907.    86.4 %     12358.
FEB  17 1974              78.0 %      5032.    94.5 %      1461.    63.1 %      3896.    75.4 %     10227.
FEB  18 1974              79.0 %      6204.    89.6 %      2846.    74.7 %      4197.    79.6 %     11313.
FEB  19 1974              85.4 %      4814.    91.5 %      2232.    81.1 %      5252.    76.7 %     15098.
FEB  20 1974              83.2 %      3651.    92.4 %      2369.    61.3 %      5883.    78.9 %     13186.
FEB  21 1974              83.2 %      7108.    88.9 %      3332.    74.7 %      5553.    79.3 %     15105.
FEB  22 1974              73.5 %      6594.    87.4 %      2836.    66.7 %      4082.    73.5 %     13965.
FEB  23 1974              78.5 %      6008.    87.9 %      2929.    81.6 %      2629.    84.5 %     10890.
FEB  24 1974              83.3 %      5100.    90.0 %      2566.    82.6 %      2458.    78.4 %     10529.
FEB  25 1974              89.5 %      4529.    76.0 %      2836.   100.0 %         0.    84.4 %     14375.
FEB  26 1974              85.1 %      4097.    89.4 %      2107.    63.8 %      2341.    69.9 %     15997.
FEB  27 1974              87.3 %      4040.    95.9 %      1385.    64.8 %      3655.    81.3 %     14621.
FEB  28 1974              94.1 %      3120.    96.3 %      1622.    83.6 %      5200.    83.0 %     14768.
MAR   1 1974             100.0 %         0.    95.3 %      1561.    82.4 %      5836.    79.4 %     16341.
MAR   2 1974              90.1 %      5832.    93.8 %      1884.    61.5 %      9422.    84.4 %     15703.
MAR   3 1974              89.2 %      4272.    96.4 %      1349.    65.8 %      5845.    81.0 %     12815.
MAR   4 1974              93.1 %      3015.    92.6 %      2366.    80.0 %      4407.    80.6 %     14150.
MAR   5 1974              74.6 %      7086.    91.6 %      2790.    70.0 %      4650.    74.2 %     18602.
MAR   6 1974              83.3 %      3735.    94.8 %      2109.    77.3 %      4394.    69.9 %     14540.
MAR   7 1974              87.9 %      3646.    94.2 %      2309.    79.6 %      3848.    75.9 %     14178.
MAR   8 1974              91.0 %      2695.    95.4 %      1617.    66.6 %      2854.    83.5 %      9829.
MAR   9 1974             100.0 %         0.   100.0 %         0.   100.0 %         0.   100.0 %         0.
MAR  10 1974              83.5 %      6426.    92.1 %      2515.    78.5 %      4173.    75.5 %     15843.
MAR  11 1974              81.8 %      8346.    93.9 %      2147.    78.6 %      5482.    77.0 %     18548.
MAR  12 1974              83.6 %      6579.    95.6 %      1554.    79.0 %      5523.    76.9 %     19674.
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FEB 13 1974  TO  MAR 12 1974          LOADING DATA SUMMARY            AUTOMATIC PLANT CONTROL

                       NH3(LBS)               NO2(LBS)               NO3(LBS)              PHOS(LBS)

                  %REMOVED|EFFLUENT     %REMOVED|EFFLUENT     %REMOVED|EFFLUENT     %REMOVED|EFFLUENT

FEB 13 1974          17.0 %     9018.     95.4 %       0.     85.7 %      61.      4.9 %      799.
FEB 14 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 15 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 16 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 17 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 18 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 19 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 20 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 21 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 22 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 23 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 24 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
FEB 25 1974          25.0 %     8271.     56.3 %      69.     62.5 %      59.     22.3 %      857.
FEB 26 1974          12.5 %     8194.     75.0 %      12.     38.5 %      94.    -75.5 %      839.
FEB 27 1974           8.2 %     6445.   -162.5 %      40.     19.4 %     112.      9.0 %      875.
FEB 28 1974          -2.3 %     4680.     87.0 %       6.     71.8 %     129.     27.8 %      909.
MAR  1 1974           8.0 %     5369.     99.4 %       0.     94.0 %      33.     13.3 %      819.
MAR  2 1974          13.6 %     4262.     99.5 %       0.     99.9 %       0.      6.8 %      803.
MAR  3 1974          13.5 %     3597.     95.4 %       0.     99.9 %       0.     19.2 %      719.
MAR  4 1974           5.9 %     3711.     55.6 %      19.     79.9 %     158.      7.5 %      997.
MAR  5 1974          10.5 %     3765.     82.8 %      11.     90.2 %      89.    -12.7 %     1118.
MAR  6 1974          15.0 %     3735.     97.2 %       2.     91.7 %      73.      8.6 %      983.
MAR  7 1974          -5.3 %     4051.     93.3 %       4.     93.2 %      47.     23.9 %      747.
MAR  8 1974          11.0 %     2822.     90.0 %       5.     91.3 %      49.      5.3 %      598.
MAR  9 1974         100.0 %        0.    100.0 %       0.    100.0 %       0.    100.0 %        0.
MAR 10 1974          -6.3 %     3518.     88.5 %       2.     65.5 %      32.     -3.3 %      990.
MAR 11 1974          12.7 %     3813.     92.3 %       4.     94.9 %      29.      2.3 %     1198.
MAR 12 1974           4.0 %     4830.     82.8 %       9.     91.9 %      62.    -14.5 %     1179.
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FEB  13 1974  TO  MAR  12 1974          FLOW DATA SUMMARY                    AUTOMATIC PLANT CONTROL
                   PLANT     MIX LIQ    MIX LIQ
                   FLOW       SVI       SS SLD      RAS        WAS
                   (MGD)                (MGL)      (MGL)      (MGL)

FEB  13 1974       24.58       0.0        0.0        0.0        0.0
FEB  14 1974       24.97       0.0        0.0        0.0        0.0
FEB  15 1974       24.36       0.0        0.0        0.0        0.0
FEB  16 1974       21.79       0.0        0.0        0.0        0.0
FEB  17 1974       19.46       0.0        0.0        0.0        0.0
FEB  18 1974       21.88       0.0        0.0        0.0        0.0
FEB  19 1974       26.24       0.0        0.0        0.0        0.0
FEB  20 1974       24.32       0.0        0.0        0.0        0.0
FEB  21 1974       26.63       0.0        0.0        0.0        0.0
FEB  22 1974       25.76       0.0        0.0        0.0        0.0
FEB  23 1974       22.51       0.0        0.0        0.0        0.0
FEB  24 1974       19.73       0.0        0.0        0.0        0.0
FEB  25 1974       23.61       0.0        0.0        0.0        0.0
FEB  26 1974       23.39       0.0        0.0        0.0        0.0
FEB  27 1974       23.07       0.0        0.0        0.0        0.0
FEB  28 1974       24.94       0.0        0.0        0.0        0.0
MAR   1 1974       27.99       0.0        0.0        0.0        0.0
MAR   2 1974       26.90       0.0        0.0        0.0        0.0
MAR   3 1974       26.96       0.0        0.0        0.0        0.0
MAR   4 1974       27.81       0.0        0.0        0.0        0.0
MAR   5 1974       26.55       0.0        0.0        0.0        0.0
MAR   6 1974       26.34       0.0        0.0        0.0        0.0
MAR   7 1974       24.29       0.0        0.0        0.0        0.0
MAR   8 1974       19.01       0.0        0.0        0.0        0.0
MAR   9 1974       22.02       0.0        0.0        0.0        0.0
MAR  10 1974       26.57      75.17    2031.25    8873.33    2029.67
MAR  11 1974       29.65      79.83    2015.00    8638.33    2141.33
MAR  12 1974       30.80      78.58    2061.58    8785.83    2182.33
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FEB  13 1974  TO  MAR  12 1974          PLANT AIR CONSUMPTION            AUTOMATIC PLANT CONTROL

    AIRFLOWS IN CUBIC FEET          ASSUMED COST -  $.000095/CF


                        AIRFLOW#1     AIRFLOW#2     AIRFLOW#3     AIRFLOW#4          TOTAL          COST


FEB  13 1974             2907063.      2276137.      2455137.      2936365.      10574702.     $  1004.60
FEB  14 1974             2740665.      2295131.      2595781.      2376613.      10008190.     $   950.78
FEB  15 1974             2851200.      2404483.      2813203.      2466815.      10535701.     $  1000.89
FEB  16 1974             2312823.      1999801.      2252857.      2146531.       8712052.     $   827.64
FEB  17 1974             1527395.      1498378.      1282506.      1357717.       5665996.     $   538.27
FEB  18 1974             1946375.      1584015.      1865238.      1453157.       6848785.     $   650.63
FEB  19 1974             2461315.      1914830.      2485939.      2500451.       9362535.     $   889.44
FEB  20 1974             3021793.      2712153.      2756473.      3277941.      11768360.     $  1117.99
FEB  21 1974             3136239.      2661753.      3322949.      3156785.      12277726.     $  1166.38
FEB  22 1974             3365932.      2684508.      3516457.      3550901.      13117798.     $  1246.19
FEB  23 1974             2817639.      2231751.      2933077.      2846003.      10828470.     $  1028.70
FEB  24 1974             2205433.      1946203.      2714921.      2382243.       9248800.     $   878.64
FEB  25 1974             3296601.      2681485.      3638821.      3438293.      13055200.     $  1240.24
FEB  26 1974             3592417.      2808797.      3737589.      3720279.      13859082.     $  1316.61
FEB  27 1974             3060791.      2476247.      2919679.      3272879.      11729596.     $  1114.31
FEB  28 1974             2665353.      2122791.      2480757.      2911419.      10180320.     $   967.13
MAR   1 1974             2585425.      2152527.      2482251.      2703235.       9923438.     $   942.73
MAR   2 1974             2097063.      1554118.      2014803.      1975190.       7641174.     $   725.91
MAR   3 1974             1627610.      1255340.      1401025.      1152986.       5436961.     $   516.51
MAR   4 1974             2259087.      1502377.      1233550.      2079326.       7074340.     $   672.06
MAR   5 1974             2545693.      2006659.      1588992.      2838611.       8979955.     $   853.10
MAR   6 1974             2500993.      2209153.      1943547.      2663987.       9317680.     $   885.18
MAR   7 1974             2753905.      2214987.      2179413.      2857547.      10005852.     $   950.56
MAR   8 1974             2850413.      2445649.      2817027.      3005081.      11118170.     $  1056.23
MAR   9 1974             2268207.      1790340.      2381085.      2377647.       8817279.     $   837.64
MAR  10 1974             1841431.      1390006.      1847817.      1787061.       6866315.     $   652.30
MAR  11 1974             2537949.      2147549.      2672695.      2870415.      10228608.     $   971.72
MAR  12 1974             2785347.      2327613.      2834237.      2980057.      10927254.     $  1038.09

    TOTAL               72561984.     59294608.     69167712.     73085376.     274109952.     $ 26040.43
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FEB  13 1974  TO  MAR  12 1974        MONTHLY EFFICIENCY SUMMARY        AUTOMATIC PLANT CONTROL


                             PRIMARY                 SECONDARY                   CHLORINATOR
                         AVE         STD         AVE         STD         AVE         STD
SS                      52.6 %      20.1 %      82.7 %       5.8 %      83.8 %       6.2 %
BOD5                    32.4 %      16.6 %      89.0 %       4.5 %      91.9 %       4.2 %
TOC                     38.9 %      16.4 %      77.7 %       7.6 %      75.3 %       8.5 %
COD                     37.9 %      16.0 %      78.4 %       4.0 %      79.1 %       5.8 %


FEB  13 1974  TO  MAR  12 1974        RESPIRATION SUMMARY               AUTOMATIC PLANT CONTROL


   UNITS - LBS LOADING / 1000 CUBIC FEET OF AERATOR TANKAGE

                      SS          BOD          TOC          COD

 AVE                 15.66        21.43        12.34        42.16

 STD                  6.66         5.95         3.36        11.53
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